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SOME FACTORS AFFECTING THE FORMATION OF COLONIES IN *GONIUM PECTORALE*

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INTRODUCTION

Gonium pectorale O. F. Müller, 1773, a chlorophyll-bearing colonial phytomonad, is frequently encountered in many bodies of fresh water. When found in abundance in nature, almost all the colonies are normal and 16-celled. Occasionally, 8- and 4-celled colonies of *G. pectorale* have been observed in nature (as by Harper, 1912; and Pascher, 1927); but any person who has attempted to maintain *Gonium* in the laboratory will be familiar with these and the many other non-16-celled forms which occur under such conditions. A culture which is more than a week old may contain forms with every number of cells from 16-celled to 1-celled. As the culture grows older, the relative number of these abnormal forms increases, until, by the end of a month, little else but 1-celled forms remains. However, a subculture made at any stage, even one consisting chiefly of 1-celled forms, goes through the same stages as did the original culture.

The formation of colonies with fewer than the normal number of cells has been reported for other colonial Phytomonadida when cultured under laboratory conditions. It has been described for *Eudorina elegans* (Hartmann, 1924), *Astrephomene gubernaculifera* (Stein, 1958a), and for a number of species of *Gonium* (Pocock, 1955). We have also observed it in *Pandorina morum* and in *Pleodorina californica*.

In *G. pectorale* this phenomenon was first reported by Harper (1912). He observed some of the 16-celled colonies split in half to form two 8-celled colonies each, and saw other colonies break apart "with a succession of sudden jerks." Hartmann (1924, 1928) found that the degeneration he observed in *Gonium* occurred sooner in more concentrated culture medium than in less concentrated. He suggested that accumulation of toxic substances was probably responsible for these abnormalities. Crow (1927), who studied the production of abnormal colonies in an evaporating culture of *Gonium* in Knop solution, believed that this progressive degeneration was due to the increasing concentration of the medium and the accumulation of organic material from the decay of colonies.

It was the purpose of the present study to investigate as fully as possible at least some of the factors which are necessary for normal colony formation in *G. pectorale*, and at the same time to explain the abnormalities so frequently encountered.

MATERIALS AND METHODS

The organisms used in this study were from a clone which was isolated from a culture supplied by Carolina Biological Supply Company, Elon College, North

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Carolina. The original 16-celled colony from which the clone was established was freed from all other protozoa by repeated isolation and transfer to sterile culture medium. Other clones of *G. pectorale* have been established from collections made in and around Franklin County, Ohio, but these show no observable differences from each other or from the clone used.

The basic culture medium used was 0.05 percent (w/v) Knop solution as used and described by Hartmann (1928). This solution was modified slightly by using a ferric citrate-citric acid solution instead of ferric chloride, and by using, except where otherwise stated, a 1/88 M carbonate buffer (1/176 M Na_2CO_3, 1/176 M K_2CO_3) (Österlind, 1949). Enough 0.54 N HCl was added to give the solution an initial pH of about 6.5. One hundred ml of culture medium were placed in each flask, except when compressed gases were used; then the volume of culture medium was 150 ml. Reagent-grade salts were used for all solutions.

All solutions were made up with water that was freshly redistilled in an all-pyrex glass still. The solutions were then filtered through a millipore filter into 250-ml Erlenmeyer flasks (Corning #5000) which had previously been sterilized by autoclaving. The flasks were then stoppered with standard-taper ground-joint stoppers (Corning #7570), or with gas inlet tubes (Corning #98100) which had Corning #39533 fritted cylinders attached on the bottom of the inlet tubes. Standard taper "Teflon" sleeves were used on all ground glass joints.

The organisms to be used as an inoculum were washed by three successive centrifugations in sterile fluid. After the flasks were inoculated they were placed in a constant temperature water bath which was kept at $20 \pm 0.1°$ C. The flasks were illuminated by eight 40-watt standard warm white fluorescent lamps which were placed under the glass bottom of the water bath. A light intensity of 600 ft-c and a photoperiod of 12 hr light and 12 hr darkness were used.

In one experiment, the cultures were aerated with compressed gases containing various concentrations of CO_2. Three mixtures of gas were used; the compressed air was obtained from the compressed air line in the laboratory; the 4 percent CO_2 (mixture with 19.9 percent O_2, 76.1 percent N_2) and the 1.2 percent CO_2 (mixture with 19.9 percent O_2, 78.9 percent N_2) were obtained from Ohio Chemical and Surgical Equipment Company, Cleveland, Ohio. The gases were bubbled through sterile distilled water and passed through sterile cotton filters before they entered the culture flasks. A flow rate of 3 ft^3/hr was maintained through each flask. All pH values were measured with a Beckman Model "G" pH meter.

On each day of an experiment, an estimation was made of the relative abundance of normal 16-celled colonies and the number of cells in each culture. A random sample was removed from each flask, fixed by heating, and placed in a Sedgwick-Rafter counting cell (A. H. Thomas No. 9945). Fifty random fields were counted on each slide with the aid of a Whipple Disk. The number of colonies observed and the total number of cells in each colony were recorded. All cultures were made in duplicate, and the values reported are the averages of the values for a pair of similar cultures.

The samples were taken at approximately the same time each day, usually the middle of the morning, but never after the middle of the afternoon. This variation in time of sampling the culture did not appreciably affect the relation of one day's growth to the next day's growth, because this clone divided only at night, usually starting about 10:30 PM. Pocock (1955) noted a similar phenomenon with the *Gonium* with which she worked; but she discovered that different populations of *Gonium* might divide at different times of day, although the time of the day at which a given strain divided remained relatively constant.

RESULTS

The influence of added carbonate.—During some preliminary experiments, it was found that the growth of *Gonium* in the ordinary 0.05 percent (w/v) Knop

solution was somewhat erratic and unpredictable, considerable differences appearing among cultures supposedly identical. Measurements of the pH of these cultures showed that most of the values were below the pH 5.5 level that Österlind (1949) had found to be critical in the growth of *Scenedesmus* in media without added carbonate. Also, preliminary experiments showed that passing CO_2, as expired air, through growing cultures of *Gonium* greatly increased the relative abundance of 16-celled colonies and produced a much richer culture. Therefore, in order to obtain a richer and more predictable growth, carbonate was added to the culture medium. Equimolar amounts of Na_2CO_3 and K_2CO_3 were added to give a final concentration of 1/88 M carbonate. This acted both as a buffer and as a source of CO_2.

The growth of cultures in carbonate-containing culture medium was compared with that in carbonate-free medium; the results are shown in table 1. As can be seen from the table, the normal 16-celled colonies are relatively much more abundant, and the rate of growth appreciably greater in the carbonate-containing medium than in the carbonate-free medium.

TABLE 1

Influence of carbonate.—A comparison of the relative abundance of normal 16-celled colonies, and of rate of growth, between cultures in 0.05% (w/v) Knop solution and cultures in 0.05% (w/v) Knop solution to which 1/88 M carbonate has been added.

Treatment	Day	Percent of total cells as 16–celled forms	Total no of cells per mm^3
No carbonate added to 0.05% Knop solution	1	42.96	1.49
	2	43.25	2.22
	3	50.41	2.89
	4	38.31	5.02
	5	39.45	9.72
	6	20.38	17.36
1/88 M carbonate added to 0.05% Knop solution	1	51.77	1.53
	2	62.09	3.11
	3	70.87	7.47
	4	63.87	12.28
	5	57.86	28.22
	6	49.43	97.20

The influence of the carbon dioxide concentration.—Cultures were grown in media which were aerated continuously with different concentrations of CO_2. The results, shown in table 2, indicate that rates of growth in 1.2 percent CO_2 and in 4 percent CO_2 were approximately the same, while that in compressed air was considerably slower. It can also be seen that the relative abundance of normal 16-celled colonies increased with the increasing concentration of CO_2.

The influence of filtrates from aged cultures.—Hartmann (1924) believed that toxic substances were produced in *Gonium* cultures, and that these substances were responsible for the abnormalities which were encountered in aging cultures. Pratt (1940) and Swanson (1943) found a growth inhibiting substance in cultures of *Chlorella vulgaris*, and Jørgensen (1956) found that *Nitzschia palea*, *Scenedesmus quadricauda*, and *Chlorella pyrenoidosa* all produced autotoxic substances.

It was decided, therefore, to investigate the influence of filtrates of aged cultures on young cultures which were in their logarithmic phase of growth. The filtrate was prepared by centrifuging the cells from an aged culture, and then filtering

the supernatant fluid through a millipore filter. Filtrate from a culture of the same age as the experimental culture was used as a control for the procedure. In addition, filtrates were prepared from cultures 1.5 weeks old, 2.5 weeks old, 3.5 weeks old, and 4.5 weeks old. On the fourth day of growth, these 5 filtrates were added to 5 different pairs of cultures, 5 ml to a flask, each pair of flasks receiving the filtrate from a differently aged culture. A sixth pair of cultures to which no filtrate was added was used as a control.

The results of this experiment are shown in table 3. It can be seen that the rate of growth drops off more rapidly in those cultures to which filtrates have been added from older cultures than in the control cultures. Moreover, a comparison of the relative abundance of 16-celled colonies shows that those cultures which had been treated with filtrates from older cultures seemed to be harmed by the filtrates. This effect was in approximate proportion to the age of the culture from which the added filtrate had been taken.

The influence of the pH of the medium.—There was some reason to suspect that the toxicity of the aged culture medium might be related to the pH of the medium.

TABLE 2

Influence of carbon dioxide.—A comparison of cultures in carbonate-buffered 0.05% (w/v) Knop solution which were aerated with gases containing different concentrations of CO_2.

Treatment	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm^3
Compressed air (0.03% CO_2)	4	26.42	7.96
	5	37.55	14.48
	6	33.57	42.88
	7	25.62	78.05
1.2% CO_2 (in 19.9% O_2+78.9% N_2)	4	40.64	12.94
	5	43.60	33.76
	6	48.55	95.10
	7	26.70	223.80
4.0% CO_2 (in 19.9% O_2+76.1% N_2)	4	59.81	12.61
	5	76.34	29.00
	6	65.99	73.48
	7	49.28	239.40

Therefore, the pH of the culture medium of the control to which no filtrate had been added, in the experiment described above, was taken each day. In addition, the pH of all cultures was taken on the eighth day. These are also listed in table 3, and from these it can be seen that the colonies seem to degenerate more rapidly, and the rate of growth is retarded, when the pH reaches a value much above 9.0.

It was desirable, therefore, to know what effect the pH of the culture medium may have on the form and the rate of growth of the colonies. Using predetermined volumes of 0.54 N HCl to regulate the pH, cultures having initial pH values of 8.4, 6.8, and 5.0 were prepared.

The results of this experiment, listed in table 4, show that the relative abundance of normal 16-celled colonies and the rates of growth are similar in the two cultures having initial pH values of 6.8 and 5.0, respectively, until the eighth day. Then both the percentage of 16-celled colonies and the rate of growth drop off more sharply in the cultures having the higher pH than in the other cultures. In the cultures having an initial pH value of 8.4, both the percentage of normal colonies and the rate of growth are considerably lower than they are in the other cultures.

The loss of ions through precipitation.—One visible difference between culture medium which has a pH value above 8 and that having a pH value somewhat below 8 is presence of precipitate in the former. Nutrient salts are precipitated from Knop solution above pH 8, thereby decreasing the concentration of these salts in the medium.

In order to determine the influence of the lessened concentration of nutrient salts caused by their precipitation in alkaline medium, the following experiment was undertaken. The culture medium was made up at pH 9.2 and allowed to stand over night. The precipitate which then formed was filtered off, and the

TABLE 3

Influence of filtrate of aged culture.—A comparison of the relative abundance of normal 16-celled colonies, and of rate of growth, between cultures to which filtrates of more aged cultures had been added and cultures which had no filtrate added. Five ml of a particular filtrate was added on the fourth day of growth of a given culture. The medium used was carbonate-buffered 0.05% (w/v) Knop solution.

Treatment	Day	pH	Percent of total cells as 16-celled forms	Total no. of cells per mm^3
No filtrate added	1	7.44	18.48	6.04
	2	7.23	8.88	9.01
	3	7.33	7.37	21.73
	4	7.43	11.29	42.54
	5	7.58	27.84	81.10
	6	7.80	57.59	242.24
	7	8.30	51.04	386.46
	8	9.09	41.11	397.40
Filtrate added from culture of same age	6		60.15	182.12
	7		52.85	391.30
	8	9.35	42.77	376.90
Filtrate added from a 1.5–week–old culture	6		56.16	225.38
	7		47.56	316.45
	8	9.55	23.14	322.00
Filtrate added from a 2.5–week–old culture	6		44.73	251.44
	7		31.80	370.20
	8	9.36	9.40	308.70
Filtrate added from a 3.5–week–old culture	6		45.92	169.70
	7		32.66	279.00
	8	9.54	7.88	271.70
Filtrate added from a 4.5–week–old culture	6		46.96	171.08
	7		22.92	245.10
	8	9.55	10.37	287.85

pH of the medium was lowered to pH 6.8, well within the normal range for *Gonium*. Nutrient salts, in half their original concentrations, were added to one portion of this medium before it was filtered into the culture flasks; no salts were added to the other portion. Both sets of flasks were then inoculated, and kept under the usual conditions.

The results of this experiment, listed in table 5, show very strikingly the detrimental effect which the loss of precipitated salts had on the form of the colony and the rate of growth. For, in the cultures with the added nutrient salts, over 75 percent of the cells were in normal 16-celled colonies on the sixth day,

while in the other culture less than 20 percent of the cells were in 16-celled colonies on the same day. Further, the cultures containing the added salts had about 21 cells/mm³, while the other cultures had only about 1/10 that much growth on the sixth day.

The influence of the iron salt.—The requirement of iron for the growth of algae is well substantiated. Pringsheim (1946) attributed some of the success of his soil-water medium to the ability of humic acids to maintain iron in an available state. Rodhe (1948) discussed the problem of the utilization of iron by certain

TABLE 4

Influence of initial hydrogen ion concentration.—A comparison of the relative abundance of normal 16-celled colonies, and of the rate of growth, among cultures having different initial hydrogen ion concentrations. The medium used was carbonate-buffered 0.05% (w/v) Knop solution.

Initial pH	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm³	pH
8.4	5	39.61	17.37	8.5
	6	47.42	41.56	8.7
	7	49.89	52.56	8.8
	8	32.90	65.30	9.0
6.8	5	54.13	63.86	7.0
	6	71.25	152.62	7.2
	7	61.60	349.50	7.7
	8	37.36	361.20	9.2
5.0	5	56.21	67.44	5.6
	6	62.72	186.54	5.9
	7	61.57	378.30	6.3
	8	54.03	509.95	7.2

TABLE 5

Influence of loss of nutrient salts by precipitation.—An investigation of the influence which the loss of nutrient salts might have on the form of the colony and on rate of growth if these salts were made unavailable to the organisms because of precipitation in the alkaline culture medium. Carbonate-buffered 0.5% (w/v) Knop solution was made up at pH 9.2, and the precipitate which formed was filtered off. The pH of the medium was then lowered to the normal range. One-half of the medium was inoculated without further change, while nutrient salts in half their original concentration were added to the other half before it was inoculated.

Treatment	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm³
Precipitate removed, no salts added	4	26.67	0.72
	5	13.80	0.85
	6	18.46	1.90
	7	9.15	2.69
Precipitate removed, one-half original concentration of salts added	4	67.69	6.22
	5	73.13	11.52
	6	76.93	21.42
	7	57.12	44.34

algae, and found that the organisms he tested could not utilize colloidal iron. He recommended the use of ferric citrate, which stayed in a form available to the algae much longer than other iron salts he used. Others (Österlind, 1949; Hewitt, 1951; and Ketchum, 1954) have discussed the role of iron in plant mineral nutrition.

In order to determine the influence of an iron deficiency on the form of the colony and on the rate of growth, cultures in a medium containing no added iron were compared with cultures containing the usual amount of ferric citrate, 0.27 mg/100 ml Knop solution.

The results of this experiment, listed in table 6, show that though the reagent-grade salts used probably had a slight "impurity" of iron in them, nevertheless those cultures containing the added iron not only had relatively more of the normal 16-celled colonies, but also grew at an appreciably faster rate. Moreover, a subculture made on the fifth day from the iron-containing culture into fresh medium with added iron had 79 percent of its cells in normal 16-celled colonies and 19.4 cells/mm^3; while a subculture from the iron-free culture into fresh iron-free medium had only 44 percent normal colonies and 11.3 cells/mm^3 when both subcultures had been growing 4 days.

TABLE 6

Influence of iron.—An investigation of the influence of iron (as ferric citrate) in carbonate-buffered 0.05% (w/v) Knop Solution on the form of the colony and on rate of growth.

Treatment	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm^3
0.27 mg ferric citrate added per 100 ml of solution	1	51.77	1.53
	2	62.09	3.11
	3	70.87	7.47
	4	63.87	12.28
	5	57.86	28.22
	6	49.43	97.20
No added ferric citrate	1	33.81	1.42
	2	62.39	2.31
	3	46.21	4.16
	4	48.18	9.62
	5	42.02	22.84
	6	29.18	66.45

The influence of the calcium ion concentration.—Another of the ions precipitated in alkaline Knop solution is the calcium ion. Though Rodhe (1948) found that 0.001 mg of calcium per liter allowed *Ankistrodesmus* to grow well, and Österlind found that this concentration of calcium also gave good growth in *Scenedesmus*, both authors found that optimum growth occurred at calcium ion concentrations of 1.0 to 5.0 mg/l. Ketchum (1954), however, states that calcium is not essential for the growth of *Chlorella*, and Arnon (1958) states that it is needed only in microquantities by green algae.

In order to determine the influence of the calcium ion concentration on the form of the colony and on the rate of growth, an experiment was planned with a series of cultures having six different calcium ion concentrations. The concentrations used were: (1) 70.0 mg/l, the amount usually in Knop solution, (2) 35.0 mg/l, (3) 7.0 mg/l, (4) 0.7 mg/l, (5) 0.07 mg/l, and (6) no added calcium. The nitrate level in the culture was kept constant by adding an equivalent amount of KNO_3 to replace the $Ca(NO_3)_2$ which would have normally been in the medium.

The results of this experiment are listed in table 7. During the period of the experiment, 5 days, the culture that contained no added calcium showed no growth. Further, by the second day, the only multicellular forms remaining were a few two-celled forms. However, all cultures containing added calcium showed appreciable growth, and all these except the culture with only 0.07 mg Ca/l, contained normal 16-celled colonies. The highest number of cells observed in a colony in the latter culture was 14 cells. In the four highest calcium concentrations, the percentage of normal 16-celled colonies increased approximately in a straight line relationship to the logarithm of the calcium ion concentration. A repetition of this experiment, using a modified Beijerinck's solution (Stein, 1958b), gave essentially the same results except that there was some slight growth in the solution that contained no added calcium.

Growth of new cultures in filtrates of aged cultures.—As stated above, Hartmann (1924) and Crow (1927) believed that toxic substances were produced in *Gonium* cultures, and that these substances were responsible for the abnormalities which they encountered in aging cultures. One of the experiments described

TABLE 7

Influence of calcium.—The relationship of the form of the colony and of the number of cells per mm^3 to the calcium ion concentration in carbonate-buffered 0.05% (w/v) Knop solution.

Treatment	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm^3
No calcium	4	0.00	2.43
	5	0.00	2.29
0.07 mg Ca/liter	4	0.00	18.14
	5	0.00	24.92
0.7 mg Ca/liter	4	7.13	21.68
	5	3.59	26.86
7.0 mg Ca/liter	4	47.41	30.16
	5	53.13	56.52
35 mg Ca/liter	4	62.93	37.85
	5	65.71	66.71
70 mg Ca/liter	4	76.11	41.24
	5	79.87	61.30

above tested the influence of filtrates from aged cultures on young cultures. Though these filtrates produced a detrimental effect, other experiments indicated that the factors responsible for this effect were probably the depletion of the CO_2, the alkalinity of the medium, and the precipitation of nutrient salts rather than the presence of a toxic substance. Therefore, correcting in large measure for these factors, another experiment was performed, in order to determine whether anything did, in fact, accumulate in an aging culture which would be detrimental to normal colony formation and normal growth.

A culture of *Gonium* was maintained for 3 weeks in 1500 ml of culture medium in a 2-l flask. At the end of this time, the pH of the solution was 9.7, and the culture consisted almost exclusively of one-celled forms, with only an occasional 2- or 3-celled form being seen. The pH of the solution was lowered to 6.5 with HCl in order to redissolve the precipitated salts. The cells were then removed by centrifugation, and the fluid was filtered through a millipore filter. Then some of the solution was again filtered, this time into sterile flasks with no further change; to another portion, half the original concentration of carbonate was first added before filtration into flasks; and to a third portion, both carbonate and

mineral salts, in half their original concentration, were added before filtration. A control in fresh carbonate-buffered Knop solution was also prepared.

The results of this experiment, listed in table 8, show that a considerable percentage of normal 16-celled colonies was produced in every culture. Further, the two sets of cultures in aged medium, to which either carbonate alone or carbonate and other salts had been added, contained almost the same percentage of normal 16-celled colonies, and grew almost as rapidly in the first 3 days as did the control in fresh medium. On the fourth day, the control had an appreciably higher percentage of normal colonies and almost one-third more cells per cubic mm than these cultures. The culture in unaltered-aged filtrate showed both normal colony formation and growth, although it did so to a lesser degree than did the other cultures.

TABLE 8

Influence of old filtrate with pH adjusted to 6.5.—The form of the colony and rate of growth of *G. pectorale* in a new culture made in the sterile filtrate of a three-week-old culture (originally carbonate-buffered 0.05% (w/v) Knop solution). The filtrate was adjusted to pH 6.5 before inoculation.

Treatment	Day	Percent of total cells as 16-celled forms	Total no. of cells per mm³
Filtrate, no salts added	1	8.89	3.60
	2	19.19	5.14
	3	37.66	19.13
	4	29.37	29.52
Filtrate, 1/176 M carbonate added	1	34.51	3.72
	2	35.54	6.69
	3	50.70	26.93
	4	23.11	44.30
Filtrate, 1/176 M carbonate, and ½ original conc. of nutrient salts added	1	29.58	3.77
	2	35.95	7.56
	3	52.66	24.97
	4	34.12	51.04
Fresh culture medium	1	32.20	3.46
	2	42.51	7.51
	3	58.74	27.33
	4	55.06	72.18

DISCUSSION

The main concern of this study has been to obtain a better understanding of those factors which promote the growth of normal colonies in *G. pectorale*. It was believed that a knowledge of factors which interfere with normal colony formation would provide information about conditions which are necessary for the growth of normal colonies.

Two main sources of non-16-celled colonies were observed. It was found, as noted also by Harper (1912) and Crow (1927), that many non-16-celled forms were produced by the break-up of pre-existing colonies. Other colonies, including most of the 8-, and many of the 4-, and 2-celled ones, seem to have been the result of what Harper (1912) called "dwarfed development in reproduction." Since a 16-celled colony is formed from a single cell in a series of four divisions, an 8-, 4-, or 2-celled colony would be produced if one or more of these divisions failed to occur. Under the normal conditions of culture used in the present study, as

represented by the controls in most experiments, the majority of the cells not included in 16-celled colonies were in colonies probably produced by this "dwarfed development." To state this unequivocally would be almost impossible, but observations made before, during, and after division strongly support this view. It would seem reasonable, therefore, to assume that those factors which influence cell reproduction also directly influence colony formation.

One of the most important of these factors is the availability of CO_2 (or carbonate) to the growing cell. Results of experiments (tables 1 and 2) seem to indicate that whenever the CO_2 concentration is sufficient for maximum growth, the majority of the dividing cells form 16-celled colonies. But, as the CO_2 supply becomes relatively less available for each cell, an increasing number of the cells stop dividing before the end of the fourth division.

Another consequence of the decreasing concentration of CO_2 throughout the life of a culture is an increase in the pH of that culture. It was found that both colony formation and reproduction are normal at pH values between about pH 5 and pH 8 (table 4). But as the pH value increases above pH 8, non-16-celled forms become more abundant and the rate of growth decreases. At pH values much above pH 9 little growth occurs, and many of the existing colonies break up.

At pH values above pH 8 some of the mineral salts of the culture medium are precipitated; the loss of these salts is detrimental both to the form of the colony and to the rate of growth (table 5). It is known that iron salts are generally insoluble in alkaline media (Granick, 1958). We have found that a shortage of iron not only results in a decreased rate of reproduction, as would be expected, but it also results in a decrease in the relative abundance of normal 16-celled colonies (table 6). Another ion which is precipitated in alkaline Knop solution is the calcium ion. Although it was found that the calcium ion is needed only in minute amounts for multiplication, it was also found that it is required in macroamounts for the maximum production of normal 16-celled colonies. Conversely, decreasing amounts of calcium result in the production of increasing numbers of non-16-celled forms, mainly through the failure of the cells of a colony to adhere to each other. Robertson (1941) and Spiegel (1954) stressed the importance of the calcium salt bridge in promoting the stability of intercellular matrices. It seems probable that the intercellular cement of *Gonium* is of the calcium salt bridge type.

Hartmann (1924) believed that the increasing inadequacy of the culture medium and the abnormalities which this produced were caused by an accumulation of toxic substances. In the present study, it appears that the detrimental effect of filtrates of aged cultures is due chiefly to the alkalinity of the filtrates (table 3). Further, if the pH of the filtrate of an aged medium is lowered to the optimum range for *Gonium*, the medium seems to be capable of supporting normal colony formation and growth. This is especially true if a replacement is made of the carbonate and the nutrient salts which have been lost to the medium either by precipitation or by utilization by the organisms (table 8). No evidence has been found for the production of an autotoxin.

SUMMARY

In ordinary laboratory cultures of *Gonium pectorale*, many or most of the colonies are abnormal, in contrast to their usual state in nature. Moreover, the proportion of these abnormal colonies increases with the age of the culture, until most are reduced to single cells.

Several factors have been found to contribute to this effect. (1) During reproduction a deficiency of CO_2 tends to inhibit cell division, resulting in 8-, 4-, or even 2-celled colonies. (2) At pH values above 8, reproduction is retarded, and forms with fewer than 16 cells become relatively more abundant. In such alkaline media some of the nutrient salts precipitate, causing a deficiency of several ions, principally iron and calcium. (3) A shortage of iron results not only in a lower

rate of cell reproduction, but also in relatively fewer normal 16-celled colonies being produced. (4) A deficiency of calcium, on the other hand, affects colony formation much more drastically than it does cell reproduction. While only a trace of calcium, 0.07 mg/1, is required for reproduction, a thousand times that amount, 70 mg/1, is required for normal colony formation. In calcium-free media, colonies will break apart.

No evidence was found to support the hypothesis that a specific autotoxin is formed in *Gonium* cultures.

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THE LIMITATIONS IN RESOLUTION AND DISCRIMINATION IN BRIGHTNESS DIFFERENCES FOR LIGHT AMPLIFIER SYSTEMS USING CONTRAST ENHANCEMENT

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INTRODUCTION

A requirement exists for light amplification in the military and scientific fields to observe phenomena that the human eye, even at its best cannot sense, or for photographing objects at light levels for which present photographic systems are not sufficiently sensitive. Furthermore, there exist many situations in which the intensification of the light is not as essential as the necessity to increase the contrast between the objects in the field of view as they are presented in the intensified image to the human eye or recording device. An effective light amplifying device, in addition to being able to detect the lowest light levels that are of interest to be presented on the reproducer, must permit an arbitrary increase in contrast. The limitations of the device should be governed only by the randomness of light itself and the randomness of the conversion of the energy of the light. At the present state-of-the-art, the only system capable of fulfilling both requirements, light intensification and contrast enhancement, is the closed circuit television light amplifier. It is possible with this kind of light amplifier to increase the contrast of the reproduced picture on the cathode-ray tube screen arbitrarily to such an extent that only a fraction of the value of the fluctuations (irregular statistical variations) in the emission from the photocathode dark current of the pick-up tube corresponds to the total brightness range of the cathode-ray tube screen. Hence, brightness differences too small to be sensed or easily overlooked by the unaided human eye may be readily perceived visually from the cathode-ray tube screen of such a light amplifier. The necessary change in contrast can easily be achieved with proper circuitry in the video amplifier of the closed circuit television system. The video amplifier circuitry can also be built in such a manner that arbitrary threshold and amplitude limiting of the signal permits any amount of the signal to be supressed, and only that portion of the signal containing pertinent information is amplified. Such an arrangement makes possible the reproduction on the cathode-ray tube screen of celestial bodies during the daytime hours without reproduction of the brightness of the daytime sky. This unique property of the closed circuit television light amplifier system permits effective daytime tracking and photographic recording of artificial satellites which otherwise, by employing conventional methods, could not be done (Gebel, 1958).

I started research work on this type of light amplifier at the Aeronautical Research Laboratory in 1952, and the first system was flight-tested in 1953 on several moonlit nights. Although the results were favorable and most observers on the flights were more than impressed, the system at that time could not provide pictures of the ground under star light alone. The objective of obtaining pictures at light levels that cannot be sensed by the unaided human eye was finally solved by developing, under contract, the intensifier image orthicon. This tube uses one or more intensifier stages in the same envelope before the storage and scanning sections of an ordinary image orthicon (Morton, Ruedy, Kelley, and Ward, 1960). The research task also investigated the use of special target plates for this type of system (Lempert, 1960). Further, special pick-up tubes producing a video signal from moving objects only have been conceived and successfully

developed under contract by the Aeronautical Research Laboratory (Gebel, 1960). The extraordinary importance of the latter pick-up tube for use in the military field and the superiority of such a light amplifier over the single or multi-stage image converter tube type light intensifier is evident and needs no further explanations.

THE LIMITATIONS IN LIGHT AMPLIFICATION

Light amplification, because of the quantum nature of light, is faced with certain limitations. The act of vision or of measuring or recording light may be considered as a counting of quanta of light for a selected exposure time and for selected areas of resolution. Due to the quantum nature of light, different elements of resolution at the focal plane, receiving their illumination from the same light source with an equal average intensity, will deviate from each other in the true count of quanta which has fallen upon them during the selected time of exposure. It is usually assumed that the probability of the deviation in the number of quanta to which the different resolution elements have been exposed corresponds to a Poisson distribution. Therefore, the standard deviation from the average is approximately the square root of the average number of the collected quanta of light during the selected exposure time and for the selected resolution area (Rose, 1948). The detector for the light, which may be, for example, a photocathode transducing the energy of the light into electrons or a photographic emulsion transducing the energy into photographic grains, may have a quantum efficiency which is small compared to unity. Then the deviation from the average number of electrons or photographic grains obtained is the limiting factor in detection, because of the randomness of the conversion of the energy and of the smaller numbers involved. The statistical distribution considered valid here is also a Poisson distribution. The fluctuation in the light focused onto the resolution element is usually neglected and the standard deviation then is determined only by using the square root of the average number of produced electrons or grains. This fundamental deviation in the number of produced electrons or photographic grains which exists between the different resolution elements for a homogeneously exposed detector is the theoretical limiting factor for detecting brightness differences between different resolution areas. If the difference in brightness between resolution elements becomes so small that the standard deviation in the number of electrons or photographic grains produced during the selected exposure time for each resolution element becomes equal to the average difference in brightness between resolution elements, then obviously the probability to detect with certainty which resolution elements belong to the brighter or the darker object is too small for practical purposes (Rose, 1948).

THEORETICAL SIGNAL TO NOISE RATIO FOR DETECTION OF LIGHT AS A FUNCTION OF RESOLUTION AND EXPOSURE TIME

In analogy to certain practices in electronics, we may consider the standard deviation from the average number of quanta of light, or the average number of produced electrons or photographic grains, as the noise and the average count as the signal. For further clarification of this terminology I shall first analyze the situation involving a detector which is divided into a large number of resolution elements of equal area. All the resolution elements have been exposed to a uniform illumination at the same time and for the same selected time duration. Then the standard deviation from the average number of electrons or grains will be the measure of the amount of deivation that has to be considered as existing between the number of electrons or grains occuring at the different resolution elements. This case applies to photographic emulsions, etc., if used as an image detector. The other situation would involve a detector whose whole area is used as one single resolution element. This single resolution element is repeatedly exposed to the

same flux of light, the exposures being of equal time duration. Here, the standard deviation will be the measure of the amount of deviation that has to be considered to exist between the counts of electrons during the different exposures. This case applies to photo cells, etc. Both cases are basically identical, as they are the result of the randomness of the conversion of the energy of light. In the following calculations the purpose for assuming the most optimistic values is to prevent unrealistic speculations, and also to provide a goal in the field of light amplification. Under these assumptions, for electronic image conversion, all noise sources are neglected except the fundamental fluctuation (irregular statistical variations) of the photoemission, expressed by the standard deviation in the average number of electrons emitted by the photocathode. For the photographic case an ideal emulsion having no inherent background is assumed.

I shall derive equations for an image detector which has a large number of resolution elements, where the resolution elements are arbitrarily selected but of equal size. In these derivations I shall deal with the electronic case, but the equations may also be applied analogously to the photographic case; then, the parameters such as "electrons", "television lines", etc., would have to be changed to the proper terminology.

I shall designate as e_p the average number of electrons produced during the selected exposure time by a selected area of resolution. As previously stated I shall ignore the fluctuation of light itself and consider only the randomness of the energy conversion process. Then I may write for the theoretical optimum signal to noise ratio, δ_e,

$$\delta_e = \frac{e_p}{e_p^{1/2}} = e_p^{1/2}. \tag{1}$$

Using the standard radiation curves for the Sun (Moon, 1940), the average number of quanta, Q_D, per mm² sec counted for a spectral region from $\lambda = 415$ mμ to 680 mμ and with a spectral composition similar to daylight, which corresponds to the illumination E_D in foot-candles, is found to be

$$Q_D \approx 10^{11} \cdot E_D. \tag{2}$$

Using this relationship and denoting with l_s the side length in mm of one square resolution element necessary to collect a sufficient number of quanta for obtaining a chosen signal to noise ratio, the exposure time as t_e in seconds, and the photocathode quantum efficiency as η_p, we may write for the number of electrons e_p occuring for one element of resolution during the selected exposure time

$$e_p = Q_D \cdot t_e \cdot \eta_p \cdot l_s^2, \tag{3}$$

and using Eq. (2) for Q_D for the spectral region as previously defined,

$$e_p \approx 10^{11} \cdot E_D \cdot t_e \cdot \eta_p \cdot l_s^2 \tag{4}$$

Eq. (4) used in Eq. (1) yields for δ_e

$$\delta_e \approx 3.2 \cdot 10^5 (E_D \cdot t_e \cdot \eta_p)^{1/2} \cdot l_s. \tag{5}$$

Rewriting Eq. (5) we find the value for l_s in mm

$$l_s \approx \frac{3.2 \cdot 10^{-6}}{E_D^{1/2}} \cdot K_1 \tag{6}$$

where

$$K_1 = \delta_e \left(\frac{1}{t_e \cdot \eta_p} \right)^{1/2}. \tag{7}$$

Figure 1 is a graphic illustration of Eq. (6) using l_s as a function of E_D with $K_1(\delta_e, t_e, \text{and } \eta_p)$ as parameters. Figure 2 compares the theoretical limit in detection of the lowest possible light level in accordance with the previous equations with the best double stage intensifier image orthicon pick-up tube. These tubes

were built by Dr. G. A. Morton and Dr. J. E. Ruedy of RCA under contracts AF33(616)–2631 and AF 33(616)–3946, initiated by the Aeronautical Research Laboratory.

For practical purposes, it is not only of interest to know the photocathode illumination, but also the lowest permissible brightness B_L in foot-lambert in the field of view as a function of l_s which can be achieved with the different possible

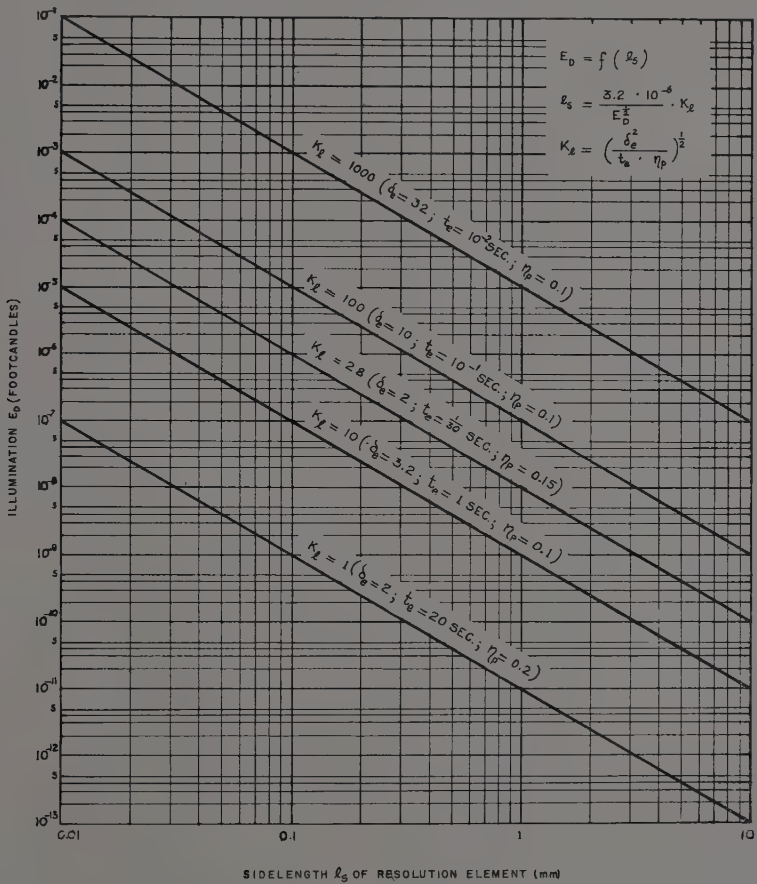

FIGURE 1. Minimum illumination of a photosensor necessary for detection as a function of the sidelength of resolution element with the indicated design parameters.

optical systems. The relationship between the illumination E_D in the focal plane and the brightness B_L is given by the well known equation

$$E_D = \frac{1}{4} \cdot \frac{B_L}{F^2} \cdot \eta_T. \tag{8}$$

where η_T is the transmission factor of the lens and F is the aperture number of the

lens ($F=\frac{f_T}{D}$, where f_T and D are the focal length and diameter of the lens system, respectively). If E_D is known as assumed in fig. 1, then the factor K_B by which E_D must be multiplied to obtain the necessary brightness of the observed area for the lens system employed may be calculated by rewriting Eq. (8)

$$K_B=\frac{B_L}{E_D}=\frac{4 \cdot F^2}{\eta_T}. \tag{9}$$

For the present state-of-the-art the efficiency η_T of the lenses may be assumed to be approximately 0.6 to 0.8, depending on the number of lens elements used and other design factors. If E_D in figure 1 is multiplied by a factor $5\ F^2$ the graph can be used for obtaining the lowest possible light levels as a function of resolution at the focal plane.

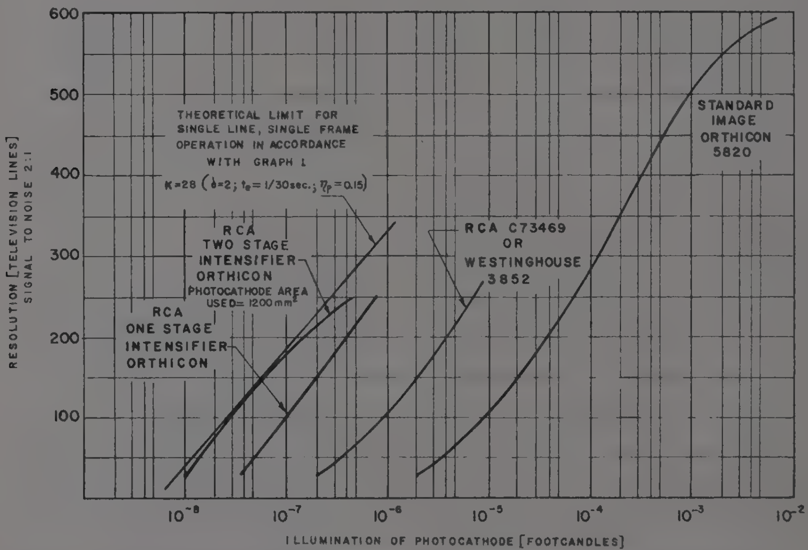

FIGURE 2. Pick-up tube performance compared to the theoretical limit of detectability.

THE PROBLEM OF CONTRAST DISCRIMINATION

In the previous section I treated some of the fundamental problems in detecting light, and I was concerned about the smallest possible area that can be detected as a function of light level, signal to noise ratio and other parameters involved. In practice, however, the problem does not consist in the detection of the lowest possible light level only, but also in detecting different objects in the field of view which requires the capability of discriminating between different brightness levels. It is of utmost importance in this field of endeavor to determine the smallest brightness difference which can be detected as a function of light level and the other design parameters involved. If I have to discriminate between an area having a brightness level of B_O in foot-lambert and another area or the background with the lesser brightness of B_B in foot-lambert, I may define as contrast C between the two areas

$$C=\frac{B_O-B_B}{B_B}=\frac{B_\Delta}{B_B}. \tag{10}$$

As stated previously, because of the quantum nature of light the instantaneous values of B_O and B_B are not constant but fluctuating, and it is usually assumed that the deviations from their average value corresponds to a Poisson distribution. It is logical to consider, as it is usually done, the probability, p, to be for practicle purposes, zero for discriminating between B_O and B_B if the difference B_Δ between the average values of B_O and B_B becomes smaller than the standard deviation of the background radiation. Furthermore, since I am dealing with detectors having a quantum efficiency of a small fraction of unity, I may neglect the deviation from the average photon number of B_O and B_B and must consider the standard deviations in the number of produced electrons. I shall designate with e_O the average number of electrons caused by B_O during the selected time at one resolu-

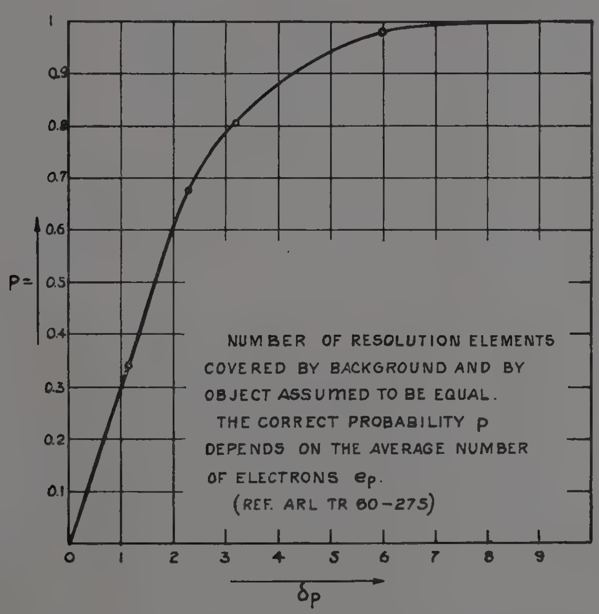

FIGURE 3. Approximate probability for discrimination between an object and surrounding background, using a photosensor.

tion element and with e_B the average number of electrons that are caused by B_B during the selected time at one resolution element; the difference between e_O and e_B we shall call e_Δ. Then in consideration of the previous statements I will arbitrarily assume here that the limit in contrast discrimination is reached when e_Δ becomes equal to the standard deviation of e_B. I may write now in accordance with our definitions

$$C=\frac{e_O-e_B}{e_B}=\frac{e_\Delta}{e_B} \tag{11}$$

and minimum contrast $c_{\lim}$ occurs when

$$e_\Delta=e_B^{1/2}. \tag{12}$$

A certain probability p of detection is assured when

$$e_\Delta = \delta_p \cdot e_B^{1/2} \tag{13}$$

where the relations between p and δ_p is shown in figure 3, which has been calculated by using a graph showing the deviation from the average number n of a Poisson distribution, which was treated in another paper of mine (Gebel and Devol, 1961).

It follows from Eqs. (4), (10), and (12) that the contrast c_{lim} which assures a certain probability of detection p is given by

$$c_{lim} \approx \frac{3.2 \times 10^{-6}}{(E_B)^{1/2}} \cdot K_D \tag{14}$$

where

$$K_D = \frac{\delta_p}{l_s}\left(\frac{1}{t_e \cdot \eta_p}\right)^{1/2}. \tag{15}$$

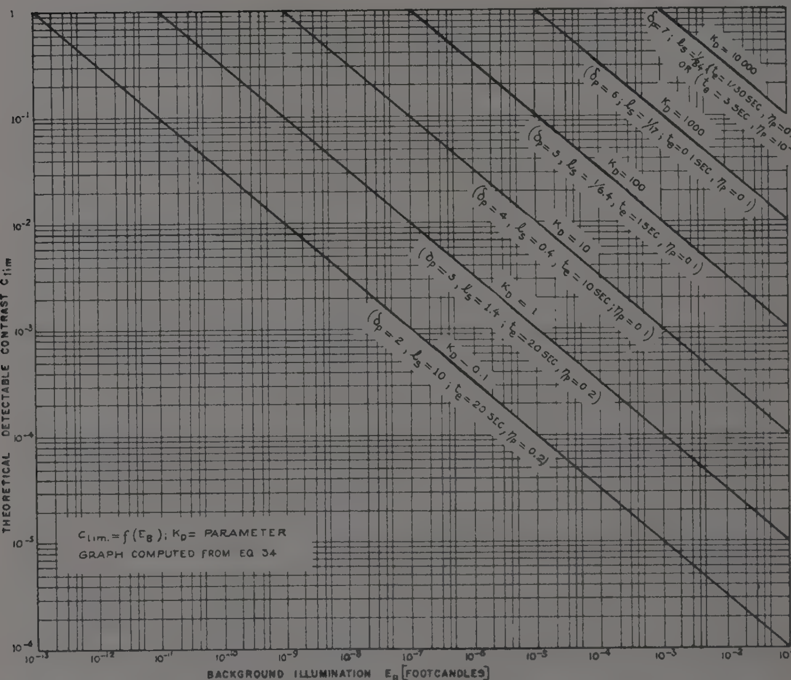

FIGURE 4. Contrast theoretically detectable by a photosensor as a function of background illumination.

To assure the proper intended use of Eq. (14), according to the assumptions used here, the selected background illumination E_B must be sufficiently high for the chosen K_D to produce, for each resolution element, an average of more than one electron, using the parameters t_e, η_p, and $\frac{1}{l}$. This situation is satisfied when

$$10^{11} \cdot E_B \cdot t_e \cdot \eta_p \cdot \frac{1}{l_s} > 1. \tag{16}$$

For practical applications, levels of background illumination producing for each resolution element during the selected exposure time only a few electrons, are not of too much concern as the limiting factor for contrast detection. The practical limitation here is usually the photocathode dark current emission (for the photographic case, fogging of the emulsion).

In Figure 4, by using Eq. (14), the limiting contrast is shown as a function of the background illumination E_B with K_D as parameter. Using Eq. (9) the neces-

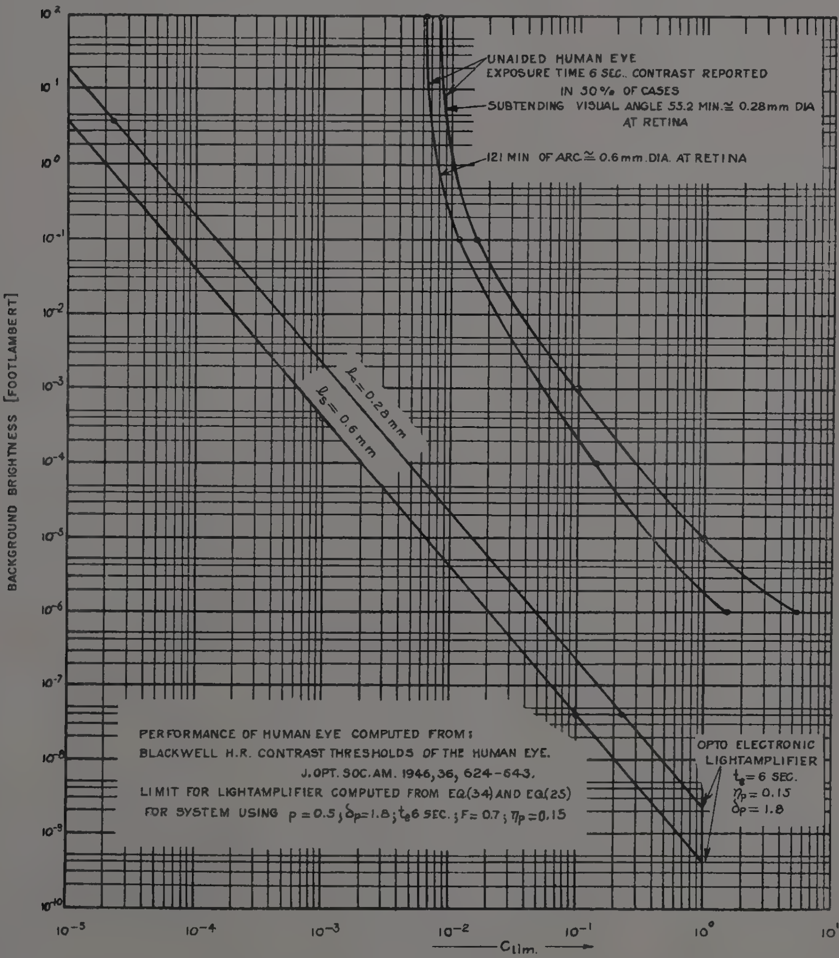

FIGURE 5. Practical threshold for contrast discrimination of the unaided human eye in comparison to the theoretical limit of closed circuit television light amplifier using contrast enhancement.

sary brightness for the object in the field of view for the lens system used may be calculated. Figure 5 compares the unaided human eye with the present state-of-the-art of a closed circuit television light amplifier, using a fast optical system and a cooled double-stage intensifier image orthicon. By cooling the primary photocathode of the intensifier image orthicon pick-up tube, the fluctuations in the photo emission process become practically the only limitations in performance which have to be considered.

CONCLUSION

As shown by figure 5 the theoretical limitations in contrast discrimination approachable with the present state-of-the-art of light amplifier systems employing contrast enhancement, suitable pick-up tubes, and lenses with high light gathering power is considerably superior to that of the unaided human eye. Factors which will determine how far the superiority can be realized in practice are: (1) sufficient quantum efficiency and homogeneity of the photocathode in the pick-up tube; (2) proper cooling of the front end of the tube to avoid the practical limitation of the photocathode dark current; (3) enough preamplification to overcome the scanning beam noise; and (4) adequate storage capability of the target plate.

ACKNOWLEDGMENTS

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Introduction to the Study of Animal Populations. *H. C. Andrewartha.* University of Chicago Press. 1961. xvii+281 pp. $5.00.

This book is designed for use as a textbook for college students of ecology. Its author views animal ecology as the science which deals with the distribution and abundance of animals, and he presents the theory and practice of conducting quantitative and experimental studies of density and dispersal. He considers at length four components of environment: the weather, other animals, food, and a place in which to live. The practical course presents methods for estimating patterns of distribution, density, and dispersal, and it emphasizes such important items as the physiological responses to temperature, the behavior in relation to moisture, food, and other animals.

This is a useful book for teachers of animal ecology and for field ecologists.

THOMAS H. LANGLOIS

PREHISTORIC HOPEWELL METEORITE COLLECTING: CONTEXT AND IMPLICATIONS

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INTRODUCTION

This paper examines and evaluates the curious practice of meteorite collecting among the prehistoric Hopewell people of Eastern North America and, more specifically, of Ohio.

The Hopewell culture complex, viewed in overall terms, covers a temporal range from approximately 400 B.C. to 400 A.D. It is not certain that this total range is applicable to the Ohio area, the center of Hopewell cultural intensity. There are indications that Ohio Hopewell began somewhat later and ended somewhat earlier than other Hopewell manifestations (Prufer, 1961). The Hopewell complex represents one of the most highly-developed prehistoric cultures of Eastern North America. It is principally characterized by a tendency toward an extreme mortuary ceremonialism expressed in the construction of large and richly furnished burial mounds and earthworks. The entire ethos of Hopewell culture appears to have been directed toward this ceremonialism. Nearly all artistic efforts, special technological skills, and a far-flung trading network were devoted to providing goods to be ultimately deposited in burials. The dichotomy between the fabulous Hopewell burial mounds and their contents, and the unspectacular Hopewell village sites is sharply apparent, especially in Ohio and Illinois, where some of the great tumuli have yielded literally thousands of ceremonial objects. The production of such objects of high quality seems to have been the main interest of the Hopewellians.

Part of this conspicuous collecting and mortuary disposal of wealth is a marked interest in exotic materials such as obsidian, from the Rockies or the Southwest, grizzly bear canine teeth from the Rockies, marine shells from Florida, native copper and silver from the Upper Great Lakes region, and mica from Virginia and the Carolinas. This interest in outlandish goods was the cause of intensive Hopewell trade which, in turn, resulted in the formation of numerous Hopewell-inspired culture groups from Florida to Wisconsin.

Among the exotic substances used by the Hopewellians, meteoric iron is conspicuous because of the obvious difficulties involved in securing it. In the Eastern United States it appears to be a horizon marker for Hopewell, since it has not been reliably reported from any other prehistoric culture complex.

Hopewell meteoric iron occurs in the form of "nuggets," i.e., unworked meteorite masses, as well as in the shape of tools and iron-foil overlay on other substances. Thus it is part of the extensive and complex pseudo-metallurgical native copper and silver technology so typical of the Hopewellians. The term pseudo-metallurgical is used advisedly, because notwithstanding the fact that Hopewell sites yielded large quantities of metal objects, these were always worked "cold"; smelting and casting remained unknown, though the native metal was frequently exposed to low heat before being worked in order to make it more malleable

OHIO HOPEWELL METEORIC IRON

Ohio Hopewell mounds have yielded numerous undisputed meteoric-iron objects as well as a few dubious instances. The latter must be listed because they were reported early in the nineteenth century, when identification of finds

were often of doubtful value. None of these finds have been preserved for re-examination. Nonetheless, as will be shown below, it is well possible that these early reports refer to meteoric iron.

The following trait list, based on published data and museum collections, gives the range of meteoric-iron objects found. In many instances more than one such object was found at any given site; this is especially true of earspools which usually occur in pairs.

1. Copper earspools, one outer plate of which is plated with meteoric iron. (Hopewell, Marriott 1).
2. Copper earspools, one side of which is covered with silver, the other with copper, while the body is made of meteoric iron. (Hopewell).
3. Copper earspools, both outer plates of which are covered with meteoric-iron overlay. (Hopewell, Harness, Fort Ancient, Turner, Porter).
4. Earspools made entirely of meteoric iron. (Porter, Turner).
5. Awls made of meteoric iron. (Seip 1, Hopewell).
6. Cylindrical beads of rolled meteoric-iron sheeting. (Seip 1, Turner, Mound City).
7. Beads made of small marine shells covered with copper sheeting which in turn is covered with meteoric iron. (Mound City).
8. Hemispherical clay, wood, or sandstone buttons covered with meteoric-iron sheeting. (Hopewell, Seip 1, Mound City).
9. Buttons consisting of small hemispheres covered with meteoric iron and set in sheet-copper settings. (Harness).
10. So-called "ceremonial" solid, rounded cones of meteoric iron. (Hopewell).
11. Fragments of meteoric-iron sheeting suggestive of plain headdresses similar to the classic Hopewell copper "helmets." (Turner, Hopewell).
12. Triple conjoined tubes or pan-pipes made of meteoric iron. (Turner).
13. Axe made of meteoric iron. (Harness).
14. Adze made of meteoric iron. (Hopewell).
15. Small straight-sided chisel made of meteoric iron. (Hopewell).
16. Curved chisels of meteoric iron imitating beaver incisors in shape. (Hopewell).
17. Small meteoric-iron drill stuck in a pearl bead which it was used to perforate. (Hopewell).
18. Small boat-shaped hollow objects of meteoric iron. (Seip 1).
19. Small disc-shaped sheets of meteoric iron. (Harness).
20. Slate cone plated with meteoric-iron foil. (Tremper).
21. Human ulna banded and partly covered with meteoric-iron sheeting. (Hopewell).
22. Ball of meteoric iron set into hollowed bear canine tooth. (Seip 2).
23. "Nuggets" of meteoric iron. (Turner, Campbell, Hopewell, Marietta).

In addition to these well-documented examples of Ohio Hopewell meteoric iron, a number of less reliable cases should briefly be dealt with. In a recent letter to me, Gregory Perino of the Gilcrease Foundation states that ". . . we bought a group of Ohio copper earspools from Dr. Young of Nashville, and a few were covered with iron." (Perino correspondence, August 10, 1961).

Atwater (1820) refers to finds of iron from such well-known Hopewell sites as Marietta and Circleville. Putnam (1883) considered these early reports untrustworthy. While in the case of Marietta there is independent evidence for meteoric iron, the Circleville find remains uncertain. Atwater states that lying on a "mirrour" of mica there was found a ". . . plate of iron, which had become an oxyde; but before it was disturbed by the spade, resembled a plate of cast iron." (Atwater, 1820: 178). In addition he refers to a silver-banded antler sleeve which

he called a knife or sword handle. While he does not claim to have found an iron blade he does state that ". . . an oxyde remained of similar shape and size." Whatever the meaning of these reports are, it should be stressed that Atwater may actually have found remains of meteoric iron at Circleville. It certainly is curious that his account pertains precisely to a Hopewell site, the only prehistoric complex from which meteoric iron has been reliably reported.

A question that immediately arises upon contemplation of the numerous finds of meteoric iron in Ohio, is whether or not these instances represent the divided-up spoils of a single meteoritic fall. An affirmative answer to this question would have far-reaching chronological implications. It would indicate that all 12 Ohio sites involved, including all major localities, were roughly contemporaneous. This certainly does not agree with other archaeological evidence (Webb and Snow, 1945; Prufer, 1961). In fact, the few analyses made of Hopewell meteoric iron indicate that individuals of different meteoritic falls were involved in the Ohio finds.

Kinnicutt (1887) analyzed three meteorite "nuggets" from two of the Turner mounds in Hamilton County, Ohio. This material is known as the Anderson meteorite. Two of the specimens were found among the rich offerings on the "altar" of mound 3. The following are Kinnicutt's findings:

type:	probably a medium octahedrite
weight:	24 grams
specific gravity:	6.42
Iron:	86.66%
Nickel:	12.67%
Cobalt:	trace
Insoluble residue:	0.10%

Well-marked Widmannstätten figures are present. Small crystals of olivine and bronzite could easily be identified under the microscope. This specimen was detached from a larger mass. There was evidence of a third, unidentified substance. The second specimen from mound 3 gave these results:

type:	probably a medium octahedrite
weight:	52 grams
specific gravity:	6.51
Iron:	88.37%
Nickel:	10.90%
Cobalt:	0.44%
Copper:	trace
Phosphorus:	trace
Insoluble residue:	0.12%

Olivine crystals could be detected. This specimen had been subjected to hammering.

The third Turner specimen analyzed was found in an "altar" deposit of mound 4:

type:	pallasite, Krasnoyarsk group (Pk) of Brezina
weight:	767.5 grams
specific gravity:	4.72

The olivine crystals of this mass had a diameter range from 5 to 10 mm. Their specific gravity was found to be 3.33, and their analysis gave these results:

SiO_2	40.02%
FeO	14.06%
MnO	0.10%
MgO	45.60%

The iron parts had a specific gravity of 7.894. They were analyzed as follows:

Iron:	89.00%
Nickel:	10.65%
Cobalt:	0.45%
Copper:	trace
Phosphorus:	trace
Insoluble residue:	0.09%

Microscopic analysis revealed the presence of bronzite. Schreibersite was surmised because of the phosphorus content.

While Kinnicutt makes it quite clear that the meteorites from mound 3 are similar, apparently representing the same fall, he also shows that the specimen from mound 4 is of a different nature. Nonetheless, the Turner meteorites are usually listed in the literature as representing one single fall. This was apparently based upon the identification of the Turner pallasite as being a fragment of the Brenham fall from Kiowa County, Kansas. This fall consists of both siderites and siderolites. It seems that by extension the two specimens from Turner 3 were classed with Brenham.

Palache has commented on this point stating that ". . . examination of the meteoric material still preserved in the Peabody Museum . . . showed that two distinct finds of meteoric iron were made there, a fact which seems to have been overlooked since the first description." (Palache, 1926: 149). Nonetheless Palache believed the Turner material to represent fragments of a single pallasite. He suggests that in the case of the mound 3 specimens, intensive hammering as exemplified by the distortion of the Widmannstätten figures, resulted in the loss of olivine. He suggests that this had been done deliberately in order to purify the metal. He further adds that, notwithstanding Kinnicutt's explicit remarks to the contrary, he could not detect traces of olivine in the two analyzed specimens from Turner 3.

Palache's findings are open to question. While there is no doubt that the irons from Turner 3 had been subjected to some hammering, it should be noted that at least one of the specimens had been cut and polished for examination. In other words, those parts of the mass were examined which had not been exposed before. It is difficult to see how the olivine inclusions, which in the case of the pallasite from Turner 4 are quite sizeable and which presumably would have been of about equal dimensions in the other specimens, had disappeared from the mass. The fact that the Widmannstätten figures in the latter pieces are perfectly recognizable, though bent, shows that the material was subjected to moderate hammering only. Furthermore, the data on specific gravity, which ever way one choses to view them, do not necessarily lead to the conclusion that the Turner 3 and 4 specimens represent a single mass.

In view of these arguments it may be preferable to consider the Turner specimens as representing two different meteorites.

The literature abounds with attempts to relate the "Anderson" material, i.e., the pallasite from Turner 4, with known meteorites. Kinnicutt (1884) compared it to the Atacama mass from Chile. Kunz (1887) thought the Turner pallasite to have been part of the Eagle Station, Carroll County, Kentucky, meteorite, because at the time this was the only other known North American pallasite which, moreover, was found only 60 miles from the Turner earthworks. Subsequent investigation (Kunz, 1890) showed that the Carroll County mass was no pallasite but a brahinite; thus the hypothesis had to be abandoned. The Turner specimen was next thought to be identical with the Brenham pallasites from Kiowa County, Kansas. Kunz argued that the ". . . fact that in connection with the large Kiowa masses a number of small portions, weighing from half a pound to six pound each, were found, makes it very probable that a small mass,

of perhaps three or four pounds, had been conveyed by the Indians to the Ohio valley." (Kunz, 1890: 318). Brezina (1895) and Wülfing (1897) agree with this view. Huntington (1891), however, finds no solid grounds for this identification, noting that it may be just as reasonable to identify the Turner mass with the Krasnoyarsk pallasite as with the Brenham masses. Farrington follows this view when he states that ". . . unless there can be traced a more positive connection than has hitherto been done, it seems better to consider Anderson separate." (Farrington, 1915: 33). In sum, it has not been possible to identify the Turner material with any known meteorites.

Farrington (1902) analyzed a heavily oxydized mass of meteoric iron found at Mound 25 of the Hopewell Group in Ross County, Ohio. The following are Farrington's findings:

type:	medium octahedrite (Om) of Brezina
weight:	130 grams
specific gravity:	not given
Iron:	95.20%
Nickel:	4.64%
Cobalt:	0.404%
Copper:	0.035%
Manganese:	trace
Tin:	trace
Sulphur:	0.13%
Phosphorus:	0.07%

Widmannstätten figures are clearly marked, though distorted as a result of hammering. Bands of kamacite separated by thin ribbons of taenite are clearly discernable. The presence of troilite and schreibersite is indicated by the percentages of sulphur and phosphorus.

The results of this analysis preclude the conclusion frequently found in the older literature that all meteoric iron found in Ohio Mounds came from the same source, ". . . the differences in percentages being greater than are known to occur among the individuals of a single fall." (Farrington, 1902: 314). Three radiocarbon dates are available for Hopewell 25. One of these, having been obtained from a composite sample (C–137) need not concern us here. It is out of line with the other dates, possibly because of its composite nature. The other two dates yielded values of 94 B.C. ±250 (sample C–139) and 1 B.C. ±200 (sample C–136) respectively (Griffin, 1958).

No other analyses of prehistoric Hopewell meteoric iron from Ohio are available. The findings indicate with certainty that the Turner and Hopewell masses are of different origin, while there is considerable evidence that the Turner 3 and 4 specimens are of different origin as well. Extending these results to the numerous other known finds of Ohio Hopewell meteoric iron, it can validly be postulated that these too, represent masses of different origins. The implications of these conclusions and assumptions will be discussed below.

EXTRA-OHIO HOPEWELL METEORIC IRON

Illinois Hopewell has yielded two documented cases of meteoric iron. One of these is the find of 22 oxydized beads, recovered from burial 10 of the Havana Mound 9 in Mason County. The metal was hammered into cylindrical shape. Nonetheless relict Widmannstätten figures, kamacite and taenite could be identified (Grogan, 1948). These beads may originally have been part of an octahedrite. Havana 9 yielded two radiocarbon dates of 386 B.C. ±256 (sample C–152) and 250 B.C. ±250 (sample M–20) respectively (Griffin, 1958).

The second instance of Hopewell meteoric iron in Illinois was communicated to me by Perino: "Several years ago L. R. Gibson of Alton, Ill., excavated what

we now call the Gibson Mound 4, and found in a log tomb containing 3 individuals, 4 pipes, beads, and 3 pairs of copper earspools. One pair had the face, or outer side, covered with a thin sheet of meteoric or other iron. . . . The Gibson Mounds are the southern group at Kampsville." (Perino correspondence, August 10, 1961).

At the Mandeville site in southwestern Georgia recent excavations (Kellar, Kelly, and McMichael, n.d.) of Mound B have yielded a burial accompanied by two copper earspools with meteoric-iron overlay. This site was clearly involved in the Hopewell trade between Ohio and the South.

The famous Crystal River site of the Santa Rosa—Swift Creek Hopewell phase on the Florida Gulf Coast yielded copper earspools covered with meteoric iron (Willey, 1949). The Murphy Island (North) site of the Hopewellian St. Johns Ia (late) phase in northern Florida yielded unspecified fragments of meteoric iron (Goggin, 1952).

In addition to these documented and identifiable instances another prehistoric find of meteoric iron east of the Mississippi should be mentioned here. This is the nickel meteorite from Oktibbeha County, Mississippi (Taylor, 1857; Farrington, 1907). This mass was found in an "Indian mound" on which no data have been recorded. Upon analysis it proved to be an ataxite of very high nickel content. The specimen weighed 5.25 grams and had a specific gravity of 6.854. The iron content was 39.69 percent while nickel accounted for 59.69 percent. In addition there were small amounts of cobalt, copper, phosphorus, aluminum, and calcium, in each case amounting to less than 1.0 percent.

No Widmannstätten figures could be detected. The metal proved to be malleable but very tough. It is uncertain whether this specimen was found in a Hopewell mound; in view of the fact that all other finds of prehistoric meteorites east of the Mississippi came from Hopewell sites, it is well possible that the Oktibbeha Mound belonged to that culture complex as well.

This brings to a close the discussion of Hopewell meteorites. In the following section the implications of these discoveries will be discussed.

CHRONOLOGY, HORIZON MARKERS, AND CEREMONIALISM

It appears to be highly significant that in Eastern North America all documented cases of prehistoric meteorite collecting are associated with Hopewell sites. Moreover a number of the older, poorly documented instances were reported from Hopewell sites as well.

Earlier in this paper allusion has been made to the older hypothesis that all Ohio Hopewell meteorites (the extra-Ohio specimens having not yet been discovered or described) represent a single fall dispersed among the Hopewellians by trade. It has been shown on the grounds of meteoritic analyses that this was not the case with the specimens examined. They represent two if not three different masses. While no analytical data are available for other Hopewell meteorite specimens, there exists independent chronological evidence indicating that many of the sites involved in this study were not contemporaneous.

Considering the problem in terms of absolute chronology, it is apparent from the radiocarbon dates for Havana 9 and Hopewell 25 that these sites are not contemporaneous. In fact, quite apart from radiocarbon dating, on the basis of ceramic stratigraphy, Havana 9 has been considered Early Hopewell in Illinois, while Hopewell 25 would be Middle Hopewell in Illinoian terms.

Within Ohio two attempts have been made to derive a relative chronology for Ohio Hopewell (Webb and Snow, 1945; Prufer, 1961). The earlier of these attempts need not be considered here since the latter is more detailed and inclusive in its analysis, considering the question in a wider framework of Eastern archaeology.

Attempting a qualitative as well as quantitative correlation of Hopewell traits with pre- and post-Hopewell phases in Ohio, and with extra-Ohio Hopewell manifestations, Prufer (1961) comes to the conclusion that the bulk of Ohio Hopewell

can be temporally equated with Middle Hopewell in Illinois. The earliest site, in this view, is Tremper, because it lacks as yet the typical Middle Hopewell ceramic complex. Mound City, nearly equally early, already has characteristic Middle Hopewell pottery, while the famed caches of effigy platform pipes at both sites place Tremper and Mound City into close chronological proximity. Harness, Seip, and Hopewell are Middle Hopewell in Ohio terms, or middle Middle Hopewell by Illinois standards. Turner is late in Ohio, and late Middle Hopewell in Illinoian terms, because of the massive appearance of stone cist burials not covered by mounds, and because of the decline of cremation practices; both traits foreshadow characteristic Late Hopewell traits in Illinois as well as Fort Ancient Aspect traits in Ohio. Latest in this sequence are the well-known hilltop fortifications such as Fort Ancient and Fort Hill, which may represent a retreat of the Hopewellians in the face of some unknown disturbance, from their great ceremonial centers in the river valleys onto the hilly mountain tops that offered defensive advantages.

If this sequence is extended to extra-Ohio Hopewell sequences it is clear that Havana 9 antedates nearly all sites in Ohio. The Gibson Mound is Middle Hopewell in Illinoian terms. The Florida sites are almost certainly late on the Middle Hopewell horizon, and there are indications that this is also true of Mandeville in Georgia. The Ohio sites represent the full chronological range of Hopewell in that state.

For the Hopewell area in general, and for Ohio-Illinois Hopewell in particular, the data clearly suggest that meteoric iron was used at various times *within* Hopewell and throughout the geographic range covered by the Hopewell complex. The implications are, in the absence of reports from other eastern prehistoric complexes, that the use of meteoric iron is a true Hopewell horizon marker.

Considering the extreme scarcity of meteoric iron and the considerable amount of knowledge required to identify this substance, the massive use of meteoric iron by the Hopewellians is nothing short of amazing. It is difficult to believe that the use of this material by the Hopewellians was dependent upon its mere accidental discovery. On the other hand, the use to which it was put fits into the general pattern of Hopewell pseudo-metallurgical techniques. The most common metal used in the manufacture of metal objects was native copper, readily available by trade from the North; similarly, native silver and galena were imported from outside sources. In none of these cases did the acquisition of raw material have to depend on either luck or the most determined sort of perseverance as in the case of seeking the heavenly bodies.

Therefore the very consistency with which meteoric iron was used by the Hopewellians throughout seems to preclude the notion that they depended upon sheer chance finds. In other words, the abundance of the material appears to be evidence for deliberate meteorite collecting. For a people so much bent on continental-wide trade, this in itself perfectly fits the picture. What were the motivations for such a postulated deliberate search?

The obvious answer to this question would seem to be at first sight that ceremonial reasons underlay meteorite collecting. Conceivably the Hopewellians at one time or another witnessed a meteoric fall which started them off on a supernaturally-charged search. In view of the overwhelmingly ceremonial orientation of Hopewell culture this would be in no way surprising. Furthermore, it should be noted that all finds of Hopewell meteoric iron were recovered from mortuary-ceremonial contexts.

On the other hand, there is the fact that the usage and treatment of meteoric iron by the Hopewellians is in no way different from that of other metals. Except for its common occurrence, there is no evidence whatever of an awareness that meteoric iron was something special. However, practically all Hopewell metal objects, including some that also served ornamental or functional purposes, had

ceremonial significance. Thus, the majority of all Hopewell copper axes shows no signs of use; there are several very large and exceedingly heavy implements of this kind which obviously could not have served functional purposes; copper headdresses and breast plates, no doubt, were used ceremonially; and many of the copper earspools occur in the hands of the dead or in rows alongside the skeletons. Many spectacular Hopewell artifacts, including meteoric iron at Turner, were found in caches, sometimes ceremonially "killed." Finally, the ceremonial character of metal objects as well as of other characteristically ornate and exotic artifacts is underscored by the fact that they have not been found at village sites. In other words, whatever ceremonial attributes meteoric iron may have had, were simply submerged in the general ceremonial character of all typical Hopewell material from the great burial structures.

I suggest that Hopewell meteorite collecting was, in part, motivated by the characteristic reverence of the Hopewellians for exotic materials which in turn were used almost exclusively in the mortuary ceremonies as a form of conspicuous consumption. A deeper motivation may have been the possibility mentioned earlier that some Hopewellians actually witnessed a meteoric fall, in which case they may have had some knowledge of the nature of meteoric iron and of how to recognize it. Ethnographic evidence from aboriginal North America for witnessed falls will be discussed in the final section of this paper.

COMPARATIVE PREHISTORIC AND ETHNOGRAPHIC MATERIAL

This is not the place to discuss the abundant references to the use of meteoric iron and to historically recorded myths and accounts of meteors and meteorites in the Old World since the time of the invention of writing. The interested reader will find compilations of such data in Beck (1880), Brezina (1904), Farrington (1900), Newton (1897), and Zimmer (1916).

References to finds of prehistoric meteorites in the Old World are far less common. By way of exemplification the finds of an iron meteorite at an Upper Palaeolithic site in Czechoslovakia (Anonymous, 1930), and of a mass in a prehistoric burial at Mordvinovka near Ekaterinoslav in Russia (Brezina, 1904) may be mentioned here.

The remainder of this discussion will be devoted to data from North America and Mexico.

Outside of the Hopewell area and context, archaeological finds of meteorites are rare. They do not show a consistent cultural pattern of distribution. In fact, authenticated associations seem to be more a matter of casual meteorite collecting, perhaps because the fall was witnessed, or because the meteorites looked out of place in the environment in which they were found. This may especially have been true in certain areas of the Southwest and on the Plains. In this connection it should be remembered that the Brenham masses were noticed by local Kansas farmers because they occurred in an area otherwise devoid of rocks.

Nininger (1938) has reported finds of stony meteorites from four archaeological camp sites in western Kansas and Colorado. He notes that these associations may be fortuitous. The same may be the case with a series of additional meteorites found at a number of archaeological surface sites west of the Mississippi (Nininger, 1952). In none of these cases, totalling nine, were the specimens worked. No data on cultural context are given.

More interesting is the find of the Winona meteorite, a siderolite, Grahamite 44 in Brezina's classification, found in 1928, 5 miles northeast of Winona in northern Arizona near a small group of prehistoric ruins (Brady, 1928). The broken mass was discovered carefully buried in a sub-floor stone cist of a kind usually found to contain burials. A similar stone cist containing an iron meteorite carefully wrapped in a feather blanket, was found in a Pueblo ruin, 100 miles south of

Winona, at Camp Verde, Arizona. Associated ceramics indicate an age of 800 to 900 years (Nininger, 1952).

Another iron meteorite, classed as finest octahedrite, was found in 1930 in the old Pueblo of Pojoaque near Santa Fe, New Mexico, in association with a very small black-on-white pot. These finds were ploughed out of the ground by an Indian. The worn condition of the meteorite suggests that it may have been part of a medicine man's paraphernalia (Brady, 1931). Nininger (1938) states that this iron was a fragment of the Glorietta mass discovered 30 miles from Pojoaque.

In 1922 a medium-sized iron meteorite, weighing in excess of 7 pounds, was found in a prehistoric ruin in Mesa Verde National Park, Colorado. Merrill states that the specimen was found ". . . commingled with miscellaneous rock fragments in the Sun Shrine at the north end of Pipe Shrine House. . . . There was nothing in its position or surroundings to indicate that the aborigines by whom it was placed realized its ultra-terrestrial origin or regarded it with other or more interest than was attached to the fragments of soft sandstone and other rock débris with which it was associated." (Merrill, 1924: 1).

The large Huizopa iron, weighing 238.5 pounds was found in a prehistoric ruin near Huizopa, Chihuahua, Mexico, 60 miles west of Temosachic (Nininger, 1932). It is possible that the building had been constructed around the meteorite.

The Casas Grandes meteorite, a medium octahedrite, was found in the prehistoric Casas Grandes ruin in Chihuahua, 150 miles south of El Paso del Norte. The discovery dates from the middle of the nineteenth century. The meteorite weighed 3,407 pounds and was found in a "sort of grave" in the middle of a room, carefully wrapped in coarse cloth. The latter was similar to shrouds enveloping the bodies in nearby graves (Farrington, 1915).

Nininger (1938) refers to a small axe, shaped from a nickel-iron meteorite fragment and excavated in an unspecified ruin in New Mexico.

Finally, the Navajo Iron should be mentioned here. This large ataxite, consisting of two masses and weighing 4,814 pounds, was found in 1922, about 13 miles from Navajo, in Apache County, Arizona. Both masses were familiar to the Navajo Indians who claim to have known about them since their arrival in the Southwest. They regarded them as sacred and had hidden them under rocks and earth (Roy and Wyant, 1949). While these data properly are part of the ethnographic discussion of this section, the fact that one of the masses bears marks made by some kind of instrument may be of archaeological interest. The Navajo disclaim authorship of these markings, attributing them to the prehistoric pottery makers. In this connection a series of pictographs on nearby rock outcroppings should be noted. In addition, human bones were found buried underneath or beside the grooved mass (Brady, 1928).

Apart from the instances cited here, no other data are available on the prehistoric utilization of meteorites in North America. It will be noted that all references are to areas west of the Mississippi, and that with the exception of Camp Verde and Winona, the finds lack the patterning and cultural exclusiveness characteristic of the Hopewell material. Nonetheless, the very fact that a fair number of the meteorites reported here were obviously treated with ceremonial reverence suggests that the prehistoric Indians had some notion as to the meteorites' special nature. On the other hand, the Mesa Verde mass and the finds on camp sites suggest no such awareness. I suggest that those meteorites accorded special treatment may have been witnessed falls or that they attracted attention because of their unusual nature and location, or both. The "unceremonial" treatment of other specimens, such as Mesa Verde, implies that the Indians did not have sufficient knowledge to identify a meteorite per se as anything out of the ordinary.

The haphazard occurrence of archaeological meteorites outside the Hopewell culture province shows that we deal here with different patterns of meteorite

collecting. In the Hopewell cases some knowledge of the mineralogical nature as well as (less certainly) of the genesis of meteorites is indicated. Combined with a profoundly ceremonial orientation and an unflagging fascination for exotic goods, this led to a determined search for meteoric iron. Elsewhere in North America the preoccupation with meteorites was casual and unsystematic, as well as unsupported by deeper curiosity or a tightly knit ceremonialism directed toward the conspicuous consumption of precious and outlandish materials. It is significant that non-Hopewell prehistoric meteorite collectors, with one exception, never attempted to work the iron into tools or ornaments. The masses were always left intact.

There remains to be discussed the ethnographic evidence available for some of the suggestions and assumptions made in the preceding paragraphs. The discussion will be restricted to Greenland and North America.

The special treatment known to have been given by Indians and Eskimos to some well-known meteorites suggests a degree of awareness of their nature, presumably similar to that discussed in connection with prehistoric meteorite collecting. The degree of sacredness in which any given meteorite was held was, however, variable. Thus, the Eskimo near Cape York, Greenland, showed only vague ceremonial and mythological interest when Lt. Peary discovered and tried to remove the large Cape York irons in the 1890's. Prior to Peary's arrival, the Eskimo had for many years fashioned implements out of the metal; such tools were known as early as 1819 to Captain Ross. The Eskimo regarded the masses as heaven sent (Farrington, 1915).

The Red River meteorites in Texas were considered sacred by local tribes, though there is no evidence that they knew anything about their extra-terrestrial origin (Farrington, 1915). Similarly there was no awareness among the Comanches that the Wichita County iron of Texas came from the skies. In fact, they do not seem to have considered it sacred until they failed to break it up and to melt it down with fires built around it (Farrington, 1915).

The Toluca meteorites of Mexico, consisting of several hundred masses, have been known since before 1776. Local inhabitants, including Indians, avidly collected the metal, forging it into tools. The Toluca irons were neither held sacred nor was there any local knowledge of their origin (Farrington, 1915).

There is evidence that at contact time the Aztecs were familiar with meteorite iron which they considered more valuable than gold.

The Iron Creek meteorite in Alberta, Canada, was considered sacred by the Cree and Blackfeet who made annual pilgrimages to this mass which was considered potent medicine. Nonetheless the Indians had no notions of its extra-terrestrial nature (Farrington, 1915).

In the case of the Willamette iron in Oregon, local Indians considered the metorite sacred, and believed it to have fallen from the moon. Similarly the Chilkoot iron of Alaska, while its sacredness is uncertain, was stated in the 1880's by its Indian owner to have been seen falling by the father of one of the tribe's oldest Indians about 100 years before. This meteorite shows signs of much handling (Farrington, 1915; Nininger, 1952).

Swanson notes, without giving his sources, that in historic times ". . . pieces of meteoric iron . . . were occasionally used for ornaments and implements . . ." by the Indians of the Southeastern United States (Swanton, 1946: 244).

Ethnographic data on beliefs regarding the origins of meteorites in general are scanty. Swanton (1928) reports that the Creek believed meteorites to have been heavenly "excrements cast upon the earth," which they mixed with their medicines. Hoffman reports a Menominee myth regarding meteorites which is worth quoting: "When a star falls from the sky, it leaves a fiery trail; it does not die, but its shade goes to the place where it dropped to shine again. The Indians sometimes find

the small stars in the prairie where they have fallen. They are of stone. . . ." (Hoffman, 1896: 210).

Reports of meteoric displays observed by Indians do not make it clear whether the aborigines connected such events with meteorites occasionally found on the earth's surface. The great display of 1833, which was observed over large parts of North America, is said to have caused great consternation among many tribes. Among the Pima in the Southwest it was considered an augury of disaster (Russel, 1908). The Kiowa referred to it for many years as the "winter that the stars fell," believing it to be a sign of danger. Similar views were held by the tribes of Missouri and some Mexican groups (Mooney, 1898). Many pictographic representations of this display and others are known from among Plains Indian tribes (Mallery, 1893). For many of these tribes it was the starting point of calendrical reckoning (Mooney, 1898).

The ethnographic evidence for Indian meteorite collecting is, on the whole, similar in pattern to that derived from prehistoric finds outside the Hopewell area. While in some cases the heavenly origin of the masses was known, in others this was not the case. Such meteorites were held to be special because of their unusual nature setting them apart from their environment. While there are some reports showing that implements were occasionally made of meteoric iron, this was not a consistent activity. In fact such practices may have been European inspired. In most cases the meteorites were considered objects of interest or veneration without being modified.

This pattern, as revealed by ethnographic sources, is quite similar to that of extra-Hopewell prehistoric meteorite collecting. It seems to be quite different from the pattern extrapolated for the Hopewell culture complex which appears to have been unique in aboriginal North America.

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Oceanography. *Mary Sears* Editor. Publ. No. 67 of the American Association for the Advancement of Science. 1961. 665 pp. $14.75 ($12.50, prepaid, to members).

"Oceanography" is a collection of the lectures which were presented, by invitation, at the International Oceanographic Congress, in New York City, August 31 to September 12, 1959. The lectures were arranged for publication in five groups, as follows: 1. History of the oceans; 2. Populations of the sea; 3. The Deep Sea; 4. Boundaries of the sea; and 5. Cycles of organic and inorganic substances in the ocean.

Fortunately for us, English has become the international language. There were lectures in this series by scientists from England, Scotland, Canada, Russia, Germany, Norway, Sweden, Denmark, Belgium, Holland, and the United States of America.

Perhaps, as Dr. Revelle states, these papers are not a summary of all existing knowledge about the oceans, but this volume contains an education for anyone who wishes to learn about the oceans. Much of the material extends far beyond the presentations of ordinary books or of briefer publications in science, making it invaluable for reference.

Thomas H. Langlois

Current Trends in Scientific Research. *Pierre Auger.* United Nations and Unesco. 1961. 245 pp. $6.75.

This "Survey of the main trends of inquiry in the field of natural sciences, the dissemination of scientific knowledge, and the application of such knowledge for peaceful ends," with a preface which explains how it came to be, is an amazing book. Its introduction is a statement of the philosophy involved in the development of research in science, of the paths from discovery to application, and of the main trends of current research.

Part One deals, chapter by chapter, with "The Fundamental Sciences, The Earth and Space Sciences, The Medical Sciences, The Food and Agricultural Sciences, Fuel and Power, and Industrial Research. Part Two covers the main trends affecting the organization of research and the dissemination of results. Part Three presents recommendations concerning scientific research, the dissemination of scientific knowledge, and the application of such knowledge for peaceful ends.

Anyone who may be working in any field of science will find great value in this book.

Thomas H. Langlois

DETERMINANTS OF CYCLIC SEDIMENTATION IN POTTSVILLE ROCKS NEAR DUNDEE, OHIO

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INTRODUCTION

A large lenticular body of sandstone occupies the middle part of the Pottsville formation (early Pennsylvanian age) in a northeast-southwest belt approximately a mile wide through Dundee, northwestern Tuscarawas County, Ohio (fig. 1). This sandstone was first identified as the Massillon sandstone by Newberry (1874, chart 2). The present study was undertaken to determine the extent, lithologic character, stratigraphic relations, and origin of this sandstone and associated rocks. Within the 51-square-mile area of study, approximately 120 stratigraphic sections were measured. Sections in surrounding areas yielded supplementary information but were not used directly in the analytical work.

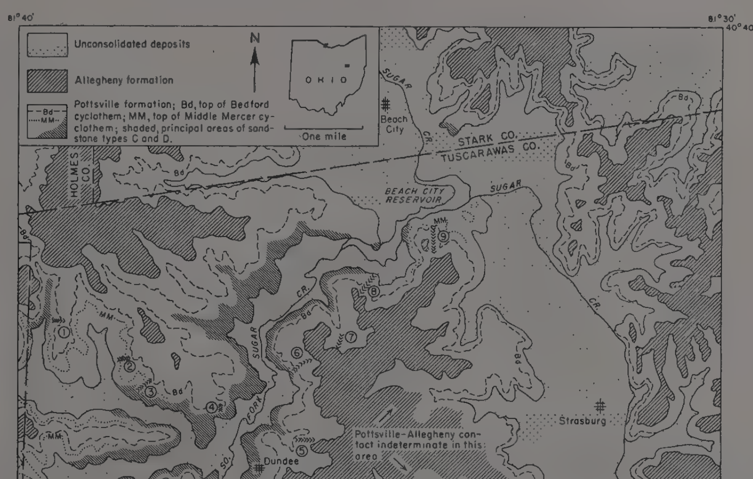

FIGURE 1. Generalized geologic map of area studied. Numbered rows of chevrons indicate locations of measured sections illustrated in figures 4 and 5. Base modified from Navarre 15-minute topographic quadrangle map of U. S. Geological Survey.

Field work for this study, most of which was supported by the Ohio Division of Geological Survey, was done principally in the summers of 1951, 1952, and 1953. Results were presented as a dissertation in partial fulfillment of the requirements for the degree Doctor of Philosophy at The Ohio State University (Gray, 1954).

STRATIGRAPHIC SUBDIVISION AND NOMENCLATURE

Traditionally, formations of Pennsylvanian age in eastern Ohio are identified with reference to key beds, most of which are thin coals or limestones. Thus the boundary between the Pottsville formation and the overlying Allegheny is placed

at the base of the Brookville coal; where this coal bed, its associated underclay, and the overlying Putnam Hill limestone, are all absent, the boundary between these formations, as presently defined, cannot be determined (fig. 1). Other coal and limestone beds, some underclays, and conspicuous bodies of sandstone are also named; these, being parts of formations, have essentially the status of members, but are rarely accorded this recognition specifically.

The principal named members that are recognized in the Dundee area are listed below in stratigraphic order:

Allegheny formation	Middle Kittanning (No. 6) coal	
	Lower Kittanning (No. 5) coal	
	Putnam Hill limestone Brookville (No. 4) coal	
Pottsville formation	Tionesta 3 coal	
	Tionesta 2 coal	
	Tionesta 1 coal	
	Tionesta (No. 3b) coal	
	Upper Mercer limestone and chert Bedford coal	
	Upper Mercer (No. 3a) coal	Stratigraphic range of the Massillon sandstone
	Lower Mercer limestone Middle Mercer coal	
	Flint Ridge (?) coal	
	Vandusen (?) coal	
	Bear Run (?) coal	

Many of the coal beds are of small extent, and the Massillon sandstone in different places occupies any part, all, or none of its indicated stratigraphic range; therefore the sequence of beds listed is not entirely exposed in any single section. The coals here called Tionesta 1, 2, and 3 are of very small areal extent and are so designated informally to avoid proposing formal names that might have little value elsewhere.

The Pottsville formation is here divided into several units for purposes of mapping, correlation, and discussion. Each of these units extends from the top of a named coal bed or equivalent stratigraphic position to the next such horizon above. The term *cyclothem* (Wanless and Weller, 1932) is here adopted, with modifications, as the generic name for these rock units. Cyclothems consist of many sedimentary members arranged in a distinctive sequence, with similarly constituted units above and below. Of the several possible places at which boundaries between cyclothems may be placed, the top of the coal is here chosen because this contact is convenient and recognizable over a wide area. As thus defined, the cyclothem can be a useful map unit.

The sequence of members recognized in Pottsville cyclothems in this area includes, in descending order:

8. Coal
7. Underclay or mudstone
6. Gray or olive-gray shale
5. Various types of sandstone
4. Gray or olive-gray shale
3. Sedimentary iron ore and (or) chert (flint)
2. Limestone, locally cherty
1. Thin gray or black shale

Because alternate lithologic types occur in most of the members, it is impossible to find all known lithologic types in a single vertical section. The sequence presented above is assembled from a large number of correlated measured sections and is, therefore, a synthetic, idealized representation.

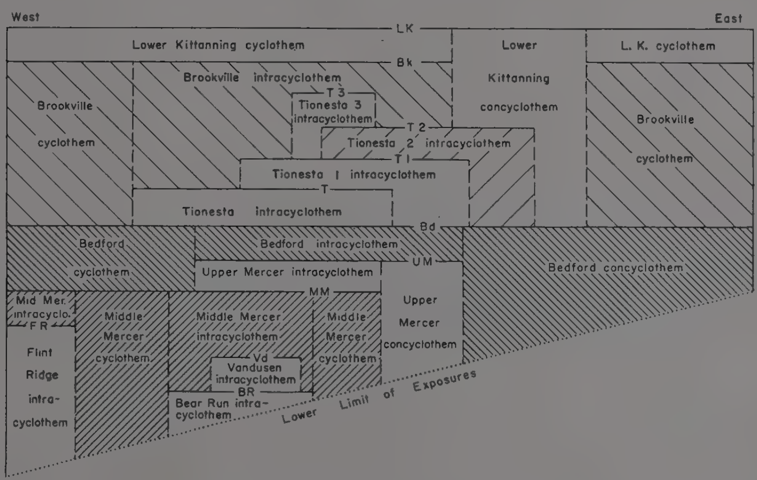

FIGURE 2. Diagram showing nomenclature of cyclic units in Pottsville formation of Dundee, Ohio, area. Solid horizontal lines are tops of named coal beds or stratigraphically equivalent horizons. Dashed vertical lines indicate lateral limits of named cyclic units. Diagram is approximately oriented on basis of available data but is not drawn to scale nor along any particular line of section.

The members most commonly represented are numbers 8 and 7, the coal and underclay. Next most frequent are the sandstones of member 5. Shales occur mostly in cyclothems that lack the sandstone; somewhat less commonly, shales underlie or overlie sandstones and occupy positions 4 or 6. Limestones of member 2 and shales of member 1 are fairly well represented, but iron ore or chert of member 3 is rare. Clastic members 4, 5, and 6 are relatively thick and constitute approximately 85 percent of most of the cyclothems of this area. The underclay-coal-black shale-limestone-chert-sedimentary iron ore sequence is an essential feature of cyclothems. If none of the units of this sequence are present, cyclothems, as here identified, cannot be distinguished.

Where additional distinctive sequences are intercalated locally into a cyclothem, cyclic units identical in kind but subordinate in rank to a cyclothem may be

TABLE 1

Interrelations and relative abundance of the common rock types

(Summarized from 40 representative measured sections aggregating 1,595 ft of exposed rocks)

Rock type	Number of exposures observed	Mean thickness (ft)	Relative abundance (%)	Common underlying rock	Nature of lower contact	Lateral equivalents	Nature of upper contact	Common overlying rock
Sandstones								
type A	15	15	15	type B sandstone gray shale	depositional	unknown	depositional	underclay
type B	5	25	8	mudrocks	erosional	unknown	depositional	type A sandstone
type C	13	20	16	mudrocks	erosional	type D sandstone type E sandstone	depositional	olive-gray shale gray shale
type D	5	25	8	unknown	unknown	type C sandstone type E sandstone	depositional	gray shale
type E	12	20	16	unknown	unknown	type C sandstone type D sandstone gray shale	depositional	mudrocks
Mudrocks								
siltstone	4	4	1	uncertain	uncertain	olive-gray shale?	uncertain	uncertain
olive-gray shale	14	13	12	coal limestone	depositional	unknown	depositional	underclay
gray shale	26	6	10	coal black shale	depositional	type E sandstone	depositional	various
black shale	6	<1	0.3	underclay olive-gray shale coal	depositional	unknown	depositional	gray shale
mudstone	4	7	2	uncertain	uncertain	unknown	depositional	coal
underclay	31	4	8	type A sandstone olive-gray shale gray shale	depositional	unknown	depositional	coal black shale limestone
Chemical rocks								
coal	27	1	2	underclay gray shale olive-gray shale	depositional	unknown	depositional	limestone gray shale
limestone	15	1	1	coal gray shale	depositional	gray shale?	depositional	olive-gray shale
chert	3	<1	0.2	coal underclay	depositional	unknown	depositional	olive-gray shale
iron ores	3	<1	0.1	limestone?	depositional	unknown	depositional	uncertain

recognized. Cyclic units thus resulting from the splitting of cyclothems are called *intracyclothems*, a term that refers to their occurrence within a cyclothem (Gray, 1954, p. 58). They may be sufficiently thick to map, but they are of lesser areal extent than cyclothems.

Where the distinctive sequence in which one boundary of a cyclothem is drawn is locally absent, that cyclothem joins with the adjacent one to form a cyclic unit identical in kind but superior in rank to a cyclothem. Cyclic sequences that thus result from coalescence of cyclothems are called *concyclothems*, a term that refers to their inclusion of the stratigraphic equivalents of parts or all of two or more cyclothems (Gray, 1954, p. 58). In the areas in which they occur they should be mapped in place of the locally unrecognizable cyclothems that they laterally replace.

The cyclothem is the basic cyclic unit in this hierarchical arrangement in much the way that the formation is the basic rock unit. The more widespread cyclic units are defined as cyclothems; intracyclothems and concyclothems are recog-

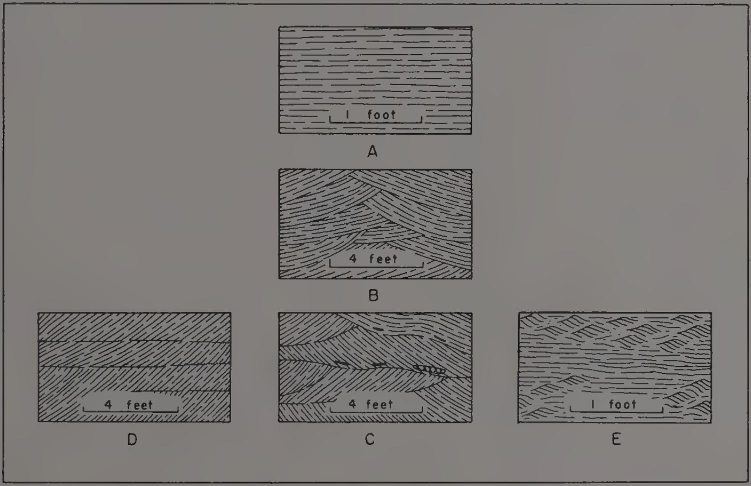

FIGURE 3. Characteristic bedding of the sandstones in Pottsville rocks near Dundee, Ohio. A, even horizontal bedding in type A sandstones; B, concave crossbedding in type B sandstones; C, crossbedding and irregular bedding in type C sandstones; D, uniformly inclined bedding in type D sandstones; E, wavy horizontal bedding in type E sandstones. Approximately to scales indicated.

nized where desirable or necessary. Cyclic units were used in mapping this area at the scale 1:24,000. Cyclothems, intracyclothems, and concyclothems are most conveniently named for the coal beds at their tops (fig. 2).

DESCRIPTION OF ROCK TYPES

Forty representative stratigraphic sections, including nearly 1,600 ft of exposed rocks, were used in compiling the descriptions that follow and the data on interrelations and relative abundance of the various rock types (table 1). A special attempt was made to describe and classify properly the nature of the contacts between rock units as an aid to the interpretation of the depositional history of the area. Contacts here described as depositional include those of transitional, interfingering, or gradational nature, any of which indicate a gradual change in

TABLE 2

Properties of the sandstones

(Averages of many field observations)

Type	Color on fresh outcrop	Bedding: Character	Bedding: Thickness	Composition: Quartz (%)	Composition: Clay (%)	Granularity	Sorting	Angularity
A	very light gray	even horizontal	thin	50	50	fine sand	fair	angular
B	very light gray	concave cross	thin to medium	65	35	fine to medium sand	fair	subangular
C	light yellow brown	cross and irregular	medium	75	25	medium to fine sand	good	subangular
D	light gray	uniformly inclined	medium to thick	90	10	medium sand	good	subangular
E	light gray	wavy horizontal	thin to very thin	60	40	very fine sand	poor	megascopically indeterminable

TABLE 3

Properties of the mudrocks

(Averages of many field observations)

Rock type	Color on fresh outcrop	Bedding: Character	Bedding: Thickness	Granularity	Fabric	Inclusions
siltstone	gray to yellow-brown	uneven	thin to very thin	silty	random to parallel	plant fossils, ferruginous concretions
shale	olive-gray	fairly even	very thin	clayey, in part silty	parallel to random	plant fossils, ferruginous concretions
shale	medium gray	even	very thin	clayey	parallel	sparse marine fossils in a few places
shale	black	even	very thin	clayey	parallel	thin coaly streaks, carbonaceous
mudstone	light gray	absent		silty and clayey	random	small root impressions
underclay	very light gray	absent		clayey, in part silty	random	*Stigmaria* in silty underclays

environmental conditions. Sharp contacts that are planar and concordant with bedding both above and below probably represent a break in deposition, a hiatus, but they lack the features distinctive of erosional contacts and in this study are also considered of depositional origin. Contacts here recognized as erosional are characterized by an uneven contact surface that is discordant with bedding of the underlying rock but broadly concordant with bedding of the overlying rock. In some places broken and somewhat worn fragments of the underlying rock or rocks are included in the beds immediately overlying an erosional contact.

Sandstones

Sandstones are the dominant rocks of the exposed part of the Pottsville in this area, as they constitute approximately 63 percent of the rocks examined in detail. The essential minerals of the sandstones are quartz and a group of argillaceous materials here referred to as clay. Morphologic variants of these argillaceous materials that were observed megascopically include (1) sand-size aggregate grains, (2) coatings on quartz grains, and (3) matrix between the grains. Very small quantities of micas, iron oxides, carbonaceous materials, and authigenic quartz as crystal overgrowths were noted in places. For a more complete petrographic description of a typical sandstone in Pottsville rocks of a nearby area, see Gray (1956).

Five sandstone types are here distinguished, mainly on the basis of bedding (fig. 3), but other properties serve to make identification more certain (table 2). It is generally possible to distinguish these types only in good exposures. There are a few borderline examples that do not clearly fall into one class or another, and still fewer that cannot be assigned to any of these five types.

Mudrocks

Mudrocks, in the sense of Ingram (1953), comprise approximately 33 percent of exposed rocks in the sections measured. If mudrocks underlie most of the covered intervals in the measured sections, as field evidence suggests, they may approach, but not exceed, an abundance of 50 percent. Mudrocks are here classified (table 3) on the basis of granularity, bedding character, and color. Fabric is indicated by orientation of mica grains. Mudrocks with parallel fabric show bedding and have a distinct platy to papery fracture; those with random fabric have hackly fracture and lack well-developed bedding. This accords with the findings of Ingram (1953).

Chemical Rocks

Coal, limestone, chert, and sedimentary iron ores are basically of chemical or biochemical origin, though each contains a subordinate amount of clastic mineral matter. These rocks are closely associated with each other, and although they constitute but 4 percent of the total rock section, they form the most widespread and distinctive individual beds in the Pottsville rocks of this area.

Chemical rocks are classified on the basis of composition. Unlike the clastic rocks, they were not observed to intergrade, and if they do, it is within very short distances; there was rarely any question, where exposures were not deeply weathered, of the nature of the chemical rock. Most of the *coals* of this area are poorly banded dull attrital coals (splints or semisplints); dull nonbanded coals (cannel or canneloid) are found locally. *Limestones* are medium gray, lack observable bedding, and are very finely crystalline. Marine invertebrates of many types are found in the limestones, but their collection and identification are difficult. The Upper Mercer limestone is commonly cherty, and is in places represented only by bedded or nodular dark gray to dark yellow-brown *chert*. Chert was not found in association with any of the other limestones in the area. *Sedimentary iron ores* are rare constituents of the measured sections.

GEOGRAPHIC DISTRIBUTION OF MEMBERS

Every member of every cyclothem in the Pottsville formation is known to be absent from its predicted stratigraphic position at some place within the area studied. These absences must result from complete local cessation of deposition, contemporaneous deposition of another sediment, or deposition followed by erosion and deposition of a younger sediment. Lateral and vertical intergradation of clastic rock types can be demonstrated graphically in some of the larger exposures, but local absence of the more widespread chemical rock types, contemporary facies equivalents of which were not discovered, is not so readily explained.

The thin Middle Mercer coal and the overlying Lower Mercer limestone are among the most areally restricted chemical rock strata. They are limited for the most part to approximately 4 square miles in the southwest corner of the mapped area (fig. 1). Elsewhere in the area of study the place of this coal and limestone

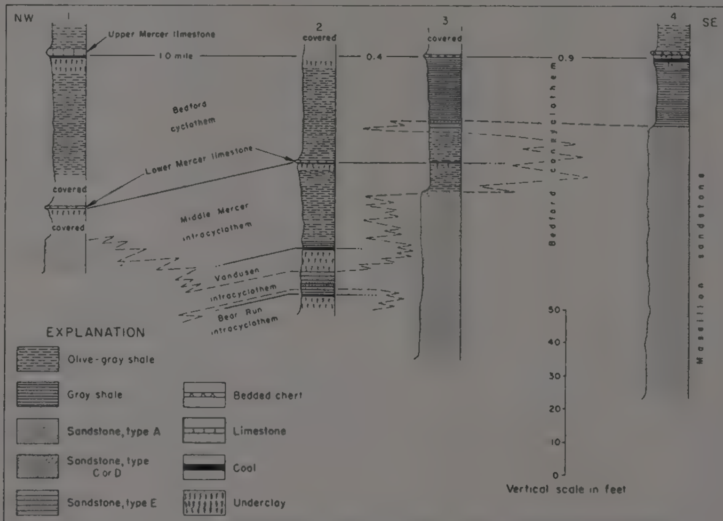

FIGURE 4. Correlated stratigraphic sections showing relation of Massillon sandstone to Lower Mercer limestone and Middle Mercer, Vandusen, and Bear Run coals. Solid correlation lines are boundaries of cyclic units; dashed lines relate sandstone bodies. Refer to figure 1 for location of measured sections.

is taken by clastic rocks, much of which is sandstone. Where thick, this sandstone is considered a part of the Massillon. Figure 4 indicates the nature of this transition where it is best seen. The coal and limestone, traced eastward from sections in which they are present in normal thickness (fig. 4, secs. 1 and 2) give way first to a thin gray shale that is underlain by a poorly developed underclay (sec. 3); this in turn is pinched out by coalescence of tongues of sandstone that lie above and below the shale (sec. 4). The exact correlation of these sandstone tongues is not certain, as exposures between sections 3 and 4 are not continuous, but scattered outcrops support the interpretation shown. Thus the top of the sandstone appears to rise stratigraphically eastward and to interfinger with the olive-gray shale that lies above the sandstone in section 3 (fig. 4); the shale apparently intervenes laterally between the sandstone body and the beds of coal and limestone.

Over a large area the main Tionesta coal has a sandstone roof (fig. 5, secs. 8 and 9). The contact between the coal and the sandstone is sharp and somewhat irregular. This suggests a disconformable relationship, but in none of the many exposures noted was this coal seen to be cut out by sandstone. Where the Tionesta coal is absent, shales most commonly are found in its place (fig. 5, sec. 6); the extent of the Tionesta coal (fig. 6, c) coincides strikingly with the area in which the part of the Brookville cyclothem below the Tionesta coal is dominantly mudrock (fig. 6, d).

The Tionesta 1 coal, which lies about 20 ft above the main Tionesta, is restricted to the south-central part of the area mapped (fig. 6, a) and lies for the most part within or adjacent to the area in which the upper part of the Brookville cyclothem is dominated by mudrocks (fig. 6, b). The Tionesta 1 coal thins and disappears northward into the area in which type A sandstones dominate the

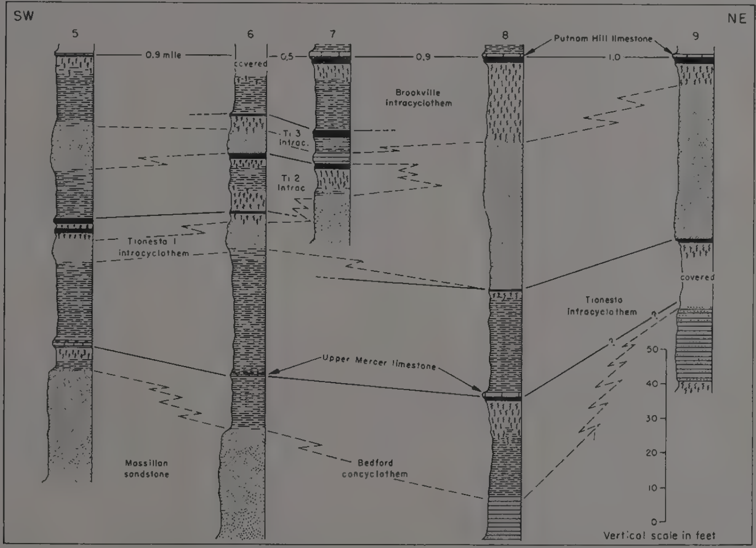

FIGURE 5. Correlated stratigraphic sections showing relations of rocks in Brookville and upper part of Bedford cyclothems. Solid correlation lines are boundaries of cyclic units; dashed lines relate sandstone bodies. Refer to figure 1 for location of measured sections.

upper Brookville. The thinning is not, however, the result of erosion (fig. 5, sec. 6); again, the top of the underlying sandstone appears to rise northeastward.

The Tionesta 2 coal has a sandstone roof, but where this coal is missing (fig. 5, sec. 5), the sandstone that takes its place has a gradational basal contact and does not suggest the filling of an erosional channel. The Tionesta 3 coal, which is of variable thickness and is restricted to a very small area, is everywhere overlain by shale (fig. 5, secs. 6 and 7). The Brookville coal ranges in thickness from 0.1 ft (fig. 5, sec. 5) to 2 ft (fig. 5, sec. 7), yet everywhere it is overlain by the very finely crystalline Putnam Hill limestone.

These examples demonstrate that thickness variations and lateral limits of the chemical rocks are not, in general, controlled by sandstone-filled erosional channels. The data instead suggest that original depositional controls are of paramount

importance. Consider the close correspondence shown between the distribution of chemical rock beds and the distribution of underlying mudrocks. It is not likely that a mudrock substratum is in some way favorable to subsequent deposition of chemical rocks; it seems more probable that this relationship results from an orderly evolution of depositional environments of limited areal scope.

ORIGIN OF THE CYCLOTHEMS

The voluminous literature on the origin of cyclothems has been summarized recently by Weller (1956). None of the many hypotheses formulated to explain cyclothems has received universal approval, but the diastrophic-control theory of Weller (1930, 1956) and the glacial-eustatic theory of Wanless and Shepard (1936) are most widely known in this country. Neither of these appears applicable to the Pottsville cyclothems in this part of Ohio because each relies heavily on a widespread disconformity as evidence of emergence and subaerial erosion.

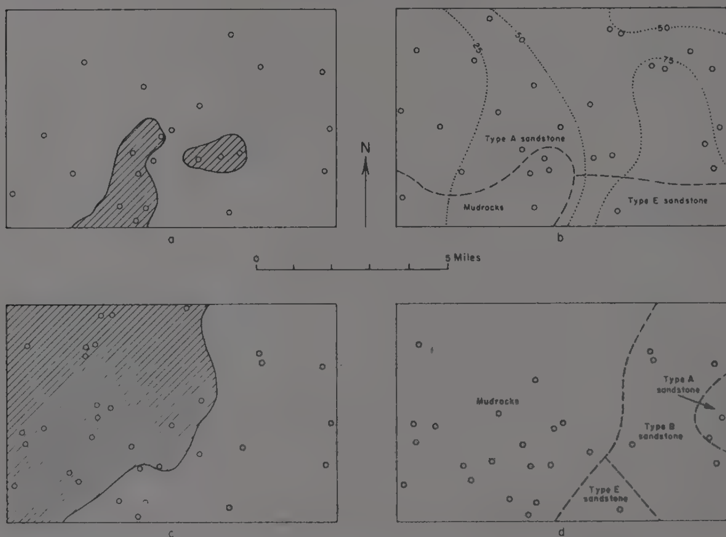

FIGURE 6. Maps showing extent of rock types in Brookville cyclothem. Area shown is same as that in figure 1. Circles indicate points of observation. a, extent of Tionesta 1 coal (ruled); b, dominant rock type in upper part of Brookville cyclothem and contours showing total sandstone content (in percent) in entire cyclothem; c, extent of main Tionesta coal (ruled); d, dominant rock type in lower part of Brookville cyclothem.

In the area studied, disconformities are commonly found, not only beneath well-developed sandstones that presumably fill channels, but within sandstone bodies as well. Between the tracts occupied by thick sandstones, in places that would necessarily have been topographically high on the old erosional surface, contacts between clastic rock bodies are characteristically transitional. It therefore seems likely that these disconformities are not continuous and do not represent regional emergence and erosion.

This does not mean that diastrophic or eustatic controls of sedimentation were inactive or ineffective in this area. Tectonic activity certainly set the determining

background for Pottsville sedimentation. Eustatic adjustments of sea level, whether caused by glaciation or otherwise, no doubt acted to negate or reinforce tectonic subsidence. Any theory proposed to explain the cyclic deposition of Pottsville rocks in this area must, however, include some type of local depositional control to explain the limited areal extent of individual members of the cyclothems.

Selective Sedimentary Traps and Sedimentary Differentiation

The various rock types recognized in this study may be classified according to the mechanical energy characteristic of their inferred environment of deposition. Mechanical energies of modern environments can be measured and are an important hydrodynamic characteristic of the environment. The assignment of an older sediment to a given environment is an inference, however, and cannot be either precise or certain; therefore, only three broad groups of environmental energies, loosely and subjectively categorized, will here be used. High-energy environments include streams and beaches in which relatively coarse sediments, such as sandstone types A, B, C, and D, accumulate. Low-energy environments include slack-water flood plains, tidal flats, and lagoons, in which finer sediments, such as type E sandstones and mudrocks, are deposited. Environments so devoid of active clastic sedimentation that deposition of chemical rock types is possible may be considered to have essentially zero mechanical energy.

In general, in the Dundee area, rock types characteristic of low-energy environments intervene between high-energy rocks and zero-energy rocks, not only vertically, but also laterally. The lateral equivalence thus implied means that there was, at any given time, areal segregation of environments of different energy levels. This segregation of environments is the most characteristic feature of Pottsville paleogeography of this area. It reflects the mechanism of control over the original distribution of individual rock bodies, and made possible the local cyclic development of Pottsville sediments.

The feature proposed as a mechanism for effecting segregation of environments of different energies is the *selective sedimentary trap*, an areally restricted depositional environment that is rather sharply distinguished physically from neighboring environments (Gray, 1954). Where an abrupt change takes place in the energy or carrying capacity of a medium of transport, a selective sedimentary trap may be established. Deposition results from energy dissipation within the trap; the coarser sediments are deposited and the finer are carried through. Deposits typical of selective sedimentary traps are offshore bars and natural levees. Both develop in narrow areas between a very high-energy environment in which erosion or transportation is dominant and a low-energy environment of relatively quiet water. Both help to confine and keep separate the dissimilar environments that border the trap.

Coarse sediments collected in high-energy selective sedimentary traps are less compactible than finer-grained sediments of adjacent low-energy environments. A physiographic high favorable for sedimentary trapping is thus maintained in a generally subsiding milieu, and the trap tends to stay in the same place through a considerable span of time. Equality of sedimentation and subsidence favors development and geographic stability of selective sedimentary traps, but traps probably can survive a small or short-lived imbalance of the two processes.

Traps are highly *effective* and collect a large proportion of the sediment passing through if the rate of energy drop within the trap is high. Traps are highly *selective* and retain only a narrow range of size grades if the energy gradient is low. Most selective sedimentary traps differentiate incoming sediments into a fraction that remains in the trap and a fraction that passes through. This process is here called *sedimentary differentiation*.

The probable course of sedimentary differentiation of the clastic rocks in the area studied can be substantiated to some extent by mathematical treatment of

the data in tables 1 and 2. If the D sandstones, which are coarse high-energy deposits, and the E sandstones, which are finer low-energy deposits, are combined on the basis of their observed quantity and composition, the result is a sediment remarkably similar to the C sandstones. If, therefore, sediment similar to that of the C sandstones were passed through a selective sedimentary trap of proper characteristics, it would be differentiated into D and E sandstones (fig. 7, bottom). There is physical substantiation for this process in the observed lateral

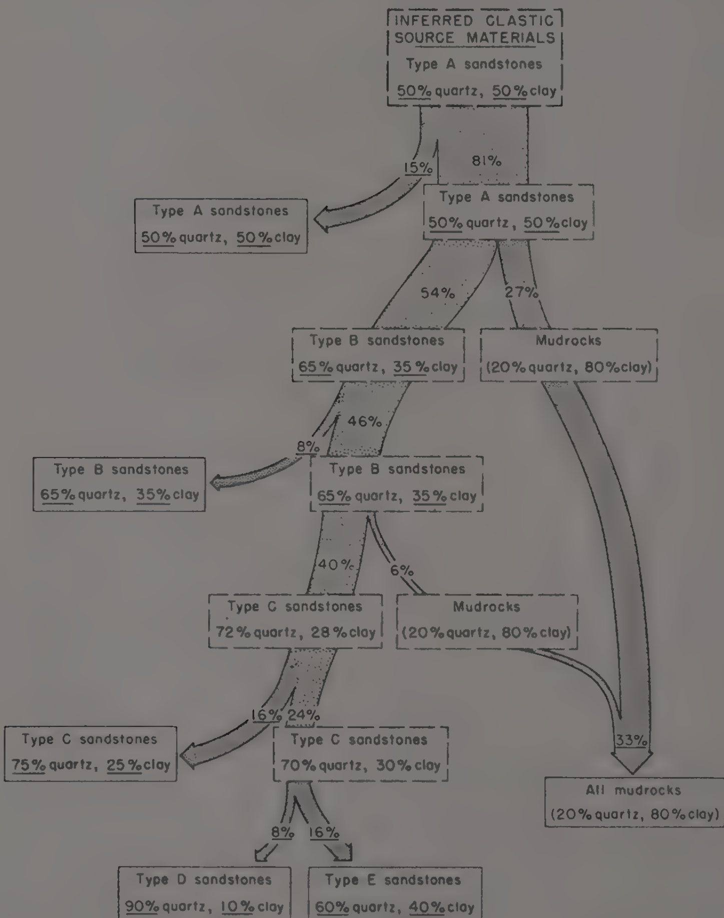

FIGURE 7. Sequence of clastic sediments formed by sedimentary differentiation in Pottsville rocks near Dundee, Ohio. Underlined figures derived or inferred from field observations; figures in parentheses assumed; all others calculated from these. Solid lines enclose observed rocks; dashed lines enclose inferred intermediate or parent sediments. Four percent of the total source material is of chemical or biochemical origin.

equivalence of these sandstone types (table 1). In like manner, the other sandstones could have been derived each from the next less quartzose sandstone type by the winnowing out of a reasonable quantity of fine constituents. By mathematical reconstitution, it can be calculated that the source material from which all the clastic rocks of this area could have been derived, by sequential differentiation in a series of selective sedimentary traps, was probably similar in composition to type A sandstone (fig. 7).

Selective Sedimentary Traps and the Deposition of Cyclothems

The particular environments represented by each of the sandstone types may be inferred from consideration of the physical characteristics of possible types of sedimentary traps. The nearly horizontal thin bedding and fair sorting of the type A sandstones suggest rather rapid deposition, possibly along natural levees and flood-plain edges. The somewhat coarser grain and relatively disorganized crossbedding of the type B sandstones perhaps reflect deposition in channel bars of aggrading streams. The oxidizing character of the environments of deposition of both sandstone types is indicated by their lack of carbonaceous material. Type

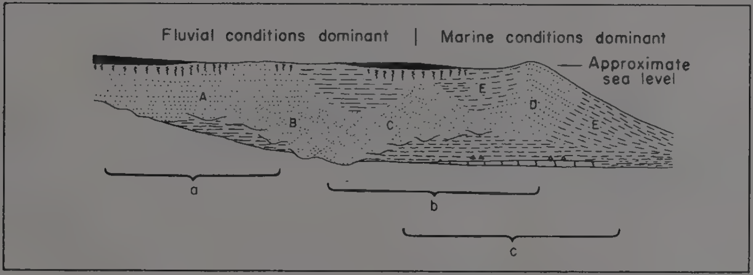

FIGURE 8. Generalized composite Pottsville-type cyclothem in profile. Length of diagram approximately 30 miles; thickness approximately 30 ft. Rock types shown in proportion to their abundance. Brackets indicate range of rock associations observed in named cyclothems within area studied; a, Brookville cyclothem; b, Bedford cyclothem; c, Middle Mercer cyclothem. Capital letters A–E designate sandstone types illustrated in figure 3 and described in table 2.

C sandstones may be delta-channel bar deposits, as suggested by the common inclusion of ferruginous and carbonaceous materials as well as by the randomly crossbedded character of these sandstones. The thoroughly worked-over, well-sorted, quartzose type D sandstones with their consistent directions of incline bedding may be deposits of beaches and offshore bars.

The E sandstones are the only type for which a precise modern analogue may be found on the basis of comparative physical characteristics. This sandstone type and its many typical small-scale sedimentary structures have been mentioned frequently in the literature of recent years (Curry and Curry, 1954; Fentress, 1955; and Shepard, 1956). There is little doubt that these are deposits of tidal flats, marine delta fronts, and aprons adjacent to offshore bars.

From a synthesis of these environmental interpretations and the known and inferred lateral relationships of the rocks in this area, a composite type cyclothem, in effect a profile drawn parallel to the depositional dip, may be assembled (fig. 8). This sequence is not seen in its entirety in any cyclothem within the area studied, but recognizable parts of it are seen, and most known vertical and lateral successions can be fitted into this general pattern. For simplicity, complications resulting from the introduction of intracyclothems and concyclothems are not shown.

A profile similarly synthesized along the depositional strike would show more gradual lateral variations, but through a much wider range of the sand-shale ratio.

In this depositional pattern it is fundamental that nearly all sedimentary types are being deposited simultaneously at one place or another, only the relative proportions being different from time to time. This is particularly true of the clastic rocks, materials for which must be delivered continually, though at times in diminished quantity, in order to maintain the trap barrier which isolates the low-energy environments in which conditions are favorable for chemical sedimentation. The necessity of a continuous clastic sediment supply required by this hypothesis even during times of widespread chemical sedimentation controverts the concept of essentially uninterrupted original sheets of homogeneous sediments called for by most other hypotheses of cyclothemic deposition, but accords well with modern analogues.

This hypothesis was formulated to account for the accumulation of cyclic assemblages of sediments in local, more or less isolated basins. Whether precise correlation between basins is possible was not determined in this study and remains to be demonstrated. All correlations involve some assumptions, and I know, at present, no way of proving exact contemporaneity of disconnected stratigraphic units that were deposited in separate basins. Such correlations may be possible if broad tectonic or eustatic controls permitted simultaneous development of traps in different areas.

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A NEW DIPLOCARDIAN EARTHWORM FROM ILLINOIS
(OLIGOCHAETA: MEGASCOLECIDAE)

W. R. MURCHIE

The University of Michigan Flint College

The species to be described here was discovered by Mr. James H. Stebbings and, at his request, is named in honor of Professor J. W. Conoyer, St. Louis University. The collection site is described by Mr. Stebbings as follows: (in manuscript)

> T2N, R8W, Section 21, St. Clair Co., Illinois. Drained by Canteen Creek, a small tributary of the Mississippi. Soil: Stookey silt loam (loessial), a soil developing on 7–15% slopes; immature Ava silt loam may be present if slope is under 7%. A_1 horizon apparent only under stable oak or elm forest. Forest; oak-hickory climax present on some slopes, sub-climax on many, sometimes dominated by large elms. Hilltops grass.

The collections were made in April and May, 1960. The material available for the following diagnosis included 14 clitellate specimens. Syntypes have been placed in the U. S. National Museum, Catalog Number 30394.

Diplocardia conoyeri n. sp.

Unpigmented (alcoholic specimens). Size, 94 to 130 by 1.7 to 2.8 mm, with averages of 116 by 2.3 mm for length and width respectively (14 clitellate specimens). Somites, 125 to 143, average 136. Form rather elongate, tapering anterior to VII, posterior end only slightly swollen. Prostomium, broad, blunt, pro-epilobic. Secondary annulations very weak. First dorsal pore 11/12. Anus terminal. Setal formula (in segment X), **aa:ab:bc:cd:** = 3:1:2:1; dd = 6aa. Clitellum XIV to XVIII, incomplete ventro-medially. Tubercula pubertatis absent. Genital tumescences, median, unpaired over 17/18 and 20/21. Spermathecal pores presetal in VIII and IX in setal line **a**; pores in VIII on anterior edge of segment, pores of IX located anterior to **a** distance equal to **ab**. Spermathecal setae not differentiated. Male field elongate, slightly raised area including XVIII to XX. Seminal gutters lunate, in setal line **ab**, from ½ XVIII to ½ XX; greatest width equals **ab**. Prostate pores at ends of gutters in XVIII and XX. Setae **ab** of XVIII and XX modified as genital setae; 1.5 x 0.01 mm in length and width; curved, with fine teeth near pointed distal end. Male pores paired on small papillae, anterior portion of XIX, in seminal gutters. Female pores, paired, anteromedial to **a**, on a transverse glandular area of segment XIV. Nephrophores in setae line **d** at anterior edge of segment.

Pharyngeal gland masses ending in IV. Gizzards in V and VI. Esophagus without distinct caliciferous gland; esophageal lumen in VII and VIII with ridged walls of columnar cells with numerous gland cells; from IX to XII, inner walls distinctly papillose, discontinuously ciliated on free ends of papillae; from XIII to ½ XVI, lumen strongly ridged with high ciliated columnar cells. Intestine expands in XVII. Typhlosole begins in XX, ends **ca** LXXV.

Last heart in XII. Subneural vessel absent. Dorsal vessel generally single, possible doubling in XIV (XII, XV?). Testes large, maniculate, from antero-ventral wall of X and XI. Sperm duct without epididymal looping; ducts on coelomic surface of parietes, joining in XVIII. Ovaries large, with multiple strands of ova, from antero-ventral wall of XIII. Ovisacs present. Ovarian funnel auriculate; oviduct direct. Seminal vesicles rather small, incised, from 9/10 and 11/12 in IX and XII. Seminal receptacles in VIII and IX; ampulla about same length as duct; elongate diverticulum opening on ento-lateral portion of duct; duct wall enlarged with definite crypt opening below diverticular stalk. Prostates two pair, opening in VIII and XX; short, narrowed duct joins gland proper in segment behind pore; glandular portion of prostate considerably longer than duct, extending through a variable number of segments (2 to 5). Regular setae unmodified. Meganephridial, avesiculate. Septa 7/8, 8/9, and 9/10 thickened; 6/7, 10/11, and 11/12 somewhat thickened.

DISCUSSION

Three species, *Diplocardia smithii* Macnab and McKey-Fender 1955, *D. udei* Eisen 1899, and *D. gracilis* Gates 1943, resemble *D. conoyeri* in: (1) location of last hearts in XII, (2) quadrithecate condition, and (3) single dorsal vessel. In the pattern of genital markings, disposition of the spermathecal pores, and structure of the penial setae, *D. conoyeri* differs from all of these species. Furthermore, it may be distinguished from *D. udei* and *D. gracilis* on the structure of the prostate glands and from *smithii* on the basis of the form of the spermathecae as well as the degree of typhlosolar development.

In those specimens of *D. conoyeri* at hand, the body wall is so transparent that it is possible to see the internal organs; particularly in the post-clitellar region; this may be the result of the method of fixation and subsequent storage in alcohol. The clitellum passes ventro-medially almost to the midline, leaving a narrow, median gland-free area which widens to *aa* on XIV and XVIII (fig. 1A). The posterior pair of spermathecal pores is displaced toward the equator of IX while those of VIII remain near the intersegmental furrow 7/8. A variation was noted in one specimen in which the anterior spermathecal pore of one side was displaced slightly posteriad on VIII.

Genital tumescences are reduced in *D. conoyeri* to unpaired median papillae across the intersegmental furrows 17/18 and 20/21. These are flattish areas, somewhat transverse, with distinct margins (fig. 1A-4). The lunate seminal gutters (fig. 1A-2) are open, possibly due to the state of fixation. Characteristically, setae *ab* of XIX are missing.

Regional differences in the esophageal region are essentially confined to the epithelial layers. In VII and VIII, "goblet-cell" types are found in the compact, non-ciliated columnar cell layer. The lumen is regular with low papillae arranged in rows. From IX through XIV, the epithelial wall is rugose because the epithelium is thrown into folds, locally separated from the muscular coat (fig. 1 B). These papillae are irregularly spaced and bear patches of cilia on their free surface. The papillae are lower or absent in XIV-$\frac{1}{2}$XV, at which point the epithelium changes abruptly, the cells becoming higher, closely packed, and heaviliy ciliated. The lining of $\frac{1}{2}$XV-XVII is ridged longitudinally, much after the fashion of a

EXPLANATION OF FIGURE 1

A. Diagram of the ventral aspect of *D. conoyeri*.
   1. Prostatic pore of XX.
   2. Seminal gutter.
   3. Spermiducal pore.
   4. Tumescence of 17/18.
   5. Glandular field surrounding female pores.
   6. Spermathecal pores.

B. Portion of esophageal wall in segment XI.
   1. Columnar epithelium.
   2. Muscular layer.
   3. Chloragogue layer.

C. Spermatheca of segment IX.
   1. Diverticulum.
   2. Crypt.
   3. Ampulla.

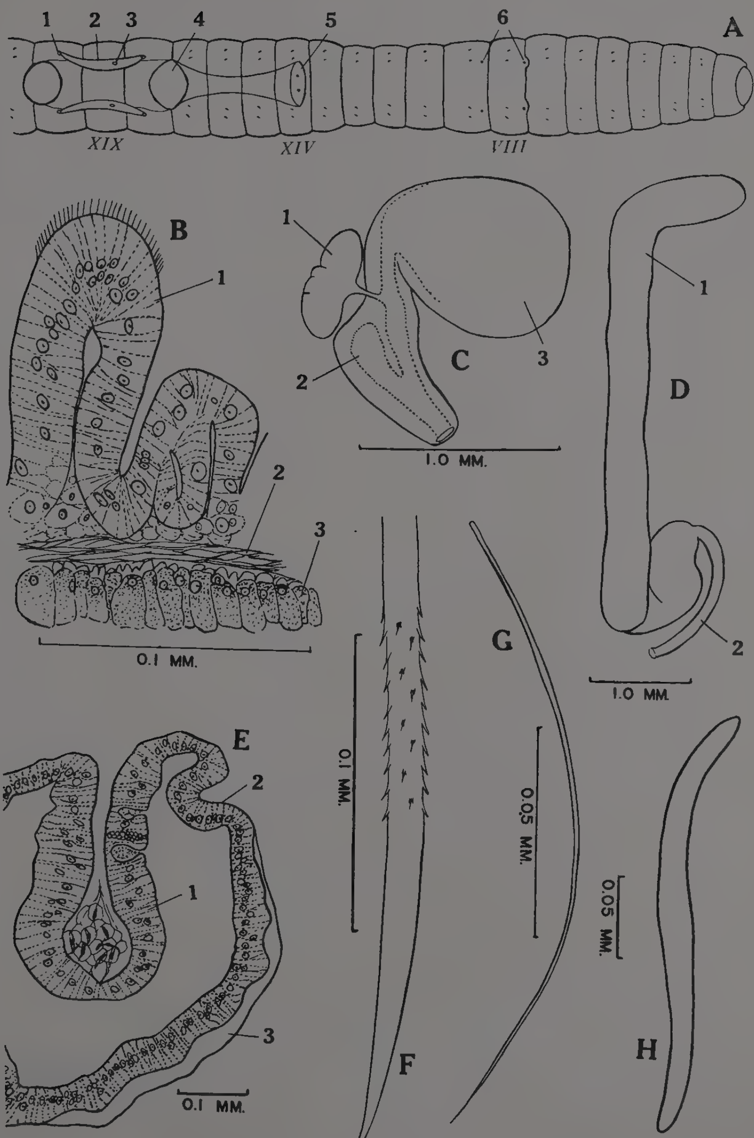
D. Prostate gland of segment XX.
   1. Glandular portion.
   2. Duct.

E. Section of intestine in segment XXI.
   1. Typhlosolar epithelium.
   2. Intestinal wall.
   3. Intestinal blood sinus.

F. Distal portion of penial seta; segment XX.

G. Penial seta of segment XX.

H. Seta of spermathecal segment VIII.



A
1
2
3
4
5
6
XIX
XIV
VIII
B
C
D
E
F
G
H
0.1 MM.
1.0 MM.
1.0 MM.
0.1 MM.
0.1 MM.
0.05 MM.
0.05 MM.

calciferous gland although the lamellae are quite low and give no hint of coalescence. A valvular structure is located at 16/17, beyond which the gut expands into the intestine proper, with a lining of low, non-ciliated columnar cells.

The dorsal vessel is generally simplex with the only apparent doubling in XIV. In XIII and XV, however, the vessel is flat and may appear, or actually be, doubled in one or both of these segments. I could not identify a supra-esophageal vessel.

The posterior spermathecae are slightly larger than those of VIII. The ampulla is rather cordate and larger than the duct. Bending of the ampulla on the duct as figured (fig. 1C), cannot be considered diagnostic as it does not always occur. Each spermathecae consists of four parts: (1) duct, (2) ampulla, (3) diverticulum, and (4) crypt. The diverticulum opens to the anterior or antero-lateral face of the duct near the ampulla. Ectally, the duct broadens, forming a shelf beneath the diverticulum. This protuberance contains an outpocketing of the duct lumen, which I have designated as a *crypt*. The structure is not unique to *D. conoyeri;* Gates, (1943) in describing *Diplocardia ornata*, has written: ". . . on the anterior face of the duct near the ampulla is a thick-walled, hemispheroidal protuberance which is continued ectally for a short distance within the wall of the duct and finally opening into the duct lumen." He continues his description, noting the presence of a "diverticulum," lateral or meso-lateral to the "protuberance" as described.

In *D. conoyeri*, the epithelial lining of the spermathecal complex is differentiated into three general regions. The duct and crypt form one region with high columnar cells, closely packed and without cilia. The ampulla is lined with columnar cells, ciliated except in the region of the juncture with the duct. The epithelium of the diverticulum is less regular; the cells appear almost cuboidal, and, as in duct and crypt, are not ciliated. In mature worms, the diverticulum is packed with sperm; the ampulla, duct, and crypt may contain a few widely distributed sperm cells.

The prostate glands each occupy more than one segment. Those of the anterior pair are more tightly coiled, involving at most three segments; the posterior pair may extend backward into XXV. The short muscular duct joins the glandular portion (fig. 1D) after penetration of the septum behind the prostatic pore. The gland may then extend directly back through successive segments or fold upon itself variously. The ectal portion of the duct passes through the body wall just lateral to the setal couple *ab* of XVIII and XX. These setae are 1.5 x 0.01 mm in length and width, nearly contiguous within the body wall, arciform, and finely-toothed distally (figs. F and G). Their follicles are quite long, passing through two post-prostatic segments to join the lateral body wall; those of XVIII reaching 20/21, of XX, to 22/23.

Two anatomical notes of some interest relate to the analysis of *D. conoyeri*. In the coelomic cavity of segment VIII, ventro-lateral to the gut, there are strands of gland cells, which, in staining reaction and form, appear to be of the same type as those found in the pharyngeal gland mass. Constancy in this structure should be looked for in other diplocardians.

The ovisac of one worm contains an ovum in metaphase; the centriole is eccentric. A similar condition is known in the Lumbricidae (Stephenson, 1930; p. 460), wherein it is suggested that the metaphasic stage obtains at the time of oviposition. Although the male funnel bears some iridescence indicating possible biparental reproduction, no other information is available on the life history of *D. conoyeri*.

The laboratory study of this material has been accomplished during the tenure of NSF Grant 6378.

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Geology of the Atlantic and Gulf Coastal Province of North America. *Grover E. Murray.* Harper & Bros. 1961. xvii+692 pp. $24.00.

Facts discovered by research workers are always detailed fragments of larger stories, and such details accumulate until some mature scientist is blessed with the time and the facilities to assemble and organize them into coherent wholes. This fundament has been realized by Murray's summary of information about the region between Newfoundland and Honduras.

The Province here considered ". . . is a coastal geosyncline consisting of an irregular mass of Mesozoic and Cenozoic sediments, grossly lenticular in the land-sea dimension and superimposed upon Paleozoic and Precambrian rocks, the surface of which dips seaward. The post-Paleozoic, commonly unconsolidated sediments of the Province, have also an overall dip seaward and at places are more than 40,000 feet thick." The extent of the region is given as 4,000 miles long, and with widths ranging from 100 to 400 miles.

No brief review can do justice to this monumental work. It presents descriptive analyses of the highlands adjacent to the coastal plain, accounts of the pre-coastal province rocks, structural geology, faults and fault systems, salt structures, regional stratigraphy, mineral resources, physiography, climate, vegetation, and soils. Each part, with its comprehensive treatment, might have been issued as a separate book, but the assembly makes sense. The author and publisher are both entitled to commendation; this book would be cheap at any price.

THOMAS H. LANGLOIS

Nematology. Fundamentals and Recent Advances with Emphasis on Plant Parasitic and Soil Forms. *J. N. Sasser and W. R. Jenkins,* Editors. The University of North Carolina Press, Chapel Hill. 1960. 480 pp. $12.50.

A National Science Foundation grant enabled recent graduates with at least some training in nematology and career nematologists to gather at North Carolina State College for intensive and advanced study, and this fine volume contains the lectures presented there in the Summer of 1959. The section headings illustrate the broad coverage of the subject and the numbers indicate the pages devoted to each section: Introduction 18, Methodology 104, Morphology and Anatomy 46, Special Treatment of Selected Nematode Groups 62, Physiology and Biochemistry 88, Genetics and Cytology 20, Ecology 78, Host-parasite Relations 20, and Control 32.

From the first chapter, Nematology—An Outlook, by Gotthold Steiner, whose life work in nematology continued long after retirement and stopped only with his death August 21, and through the last chapter on Chemical Control (of less than three pages) by A. L. Taylor, the basic aspects of nematology are comprehensively treated. Chapters by Dropkin, Boell, von Brand, Fairbairn, Dougherty, and Mulvey on methodology, physiology, and genetics should have wide appeal to students of the invertebrates.

This excellent treatise on nematodes is well illustrated, indexed, and nicely printed and bound. It must be considered a necessary book for many phytopathologists and zoologists.

CARL VENARD

Fluid Dynamics and Heat Transfer. *J. G. Knudsen* and *D. L. Katz.* McGraw-Hill Book Company, Inc., New York. 1958. viii+576 pp. $13.50.

This text is clearly intended for the advanced student or research and development worker in this area. Its clarity and scope recommend it highly for both reference and study.

A general study of convection-heat transfer for incompressible fluids is approached by a thorough study of flow of nonviscous and viscous fluids. Extensive material on laminar and turbulent flow of viscous fluids, including an up-to-date review of the laminar sublayer in turbulent flow, is presented as a solid foundation for the study of convection heat transfer. A chapter on heat transfer with liquid metals is included, as well as a brief but lucid introduction to conformal mapping. Those concerned with the historical or human aspects of fluid mechanics will find a treatment of the interesting Nikuradse case: "It appears that Nikuradse shifted his original data in order that his velocity distribution near the wall of the tube would agree with Prandtl's laminar sublayer theory."

Although this volume has been published in the McGraw-Hill Series in Chemical Engineering, it is clearly of interest to mechanical and aeronautical engineers, not to mention certain areas of applied mechanics and physics.

CHARLES D. NASH, JR.

THE AMERICAN UPPER ORDOVICIAN STANDARD. VI. THE COVINGTON SEQUENCE AT MAYSVILLE, KENTUCKY

JAMES W. CARPENTER AND THOMAS R. ORY

Department of Geology, The Ohio State University, Columbus, 10

INTRODUCTION

Within the past decade, U. S. Highway 62–68 has been re-routed south of Maysville, Kentucky, and some 350 ft of Upper Ordovician strata have been exposed in unbroken sequence. Such thick, continuous exposures are not common in the Cincinnati region of Ohio, Kentucky, and Indiana, and this one would be of more than ordinary interest for that reason alone. In addition, this section is near the eastern limits of Ordovician exposure in the Cincinnati region, and thus provides detailed information as to the faunal and lithologic successions 75 miles southeast of Cincinnati where type sections of most local Upper Ordovician formations occur.

Location. The area of study is at the southern outskirts of Maysville, Kentucky, approximately 1.2 miles south of the south end of Maysville-Aberdeen bridge along U. S. Highway 62–68. The Eden, Fairview, and McMillan formations are well exposed in six roadcuts along the west-trending highway. These exposures are in the south half of the southeast rectangle of the Maysville West $7\frac{1}{2}$ minute quadrangle (1952), west from the school up the west-trending valley next south of the reservoir.

In order to describe this section accurately, we prepared a large-scale plane-table map of it (fig. 1), from which was drawn a vertically exaggerated cross-section (fig. 2) showing the boundaries between formations of the Maysville group exposed in the section. Rock and fossil specimens were collected systematically from all units exposed and studied in the laboratory. The ranges of the more significant mega- and microfossils are indicated in figure 3.

Acknowledgements.—The field and laboratory studies on which this report is based were conducted during the 1959–60 academic year and were financed by a National Science Foundation Undergraduate Research Participation Grant (G8178). Equipment was furnished by the Department of Geology, The Ohio State University. This paper is the result of a joint effort, but it should be pointed out that the paleontology was handled primarily by Carpenter and the lithology mainly by Ory. We are indebted to Professors Walter C. Sweet and Malcolm P. Weiss of The Ohio State University, who supervised the research.

THE LITHOLOGIC SEQUENCE

Covington Group

The shales of the Covington group were not studied intensively by us but the shale-limestone ratio in each member may prove valuable for identification. Shales of two colors dominate--dark yellow-brown (10YR4 2) and medium gray (N5). All of the shales are fissile. In the lower third of the group, shales predominate; whereas in the upper two-thirds shales are thin and are only a minor feature of the lithology. The principal megafossils of the shales are bryozoans and brachiopods. The bryozoans occur in lenses on the upper surfaces of many shale beds.

The limestones range from those that are coarse-grained, fossiliferous, and have a low silt-clay content, to those that are microgranular, unfossiliferous, and have a high silt-clay content and low-angle cross-bedding.

The relatively coarse-grained limestones are composed almost exclusively of

whole and broken bryozoans and brachiopods. A very few of the limestones are nearly pure calcium carbonate. Most limestones have some silt and clay impurities. The limestones were classified according to the system of Weiss and Norman (1960). Limestones of different classes occur randomly throughout the exposed part of the Covington group, but there are concentrations of some types that will be described for each member.

The lower third of the group consists mostly of shale, with prominent limestone ledges spaced farther apart than in the upper two-thirds of the section. A

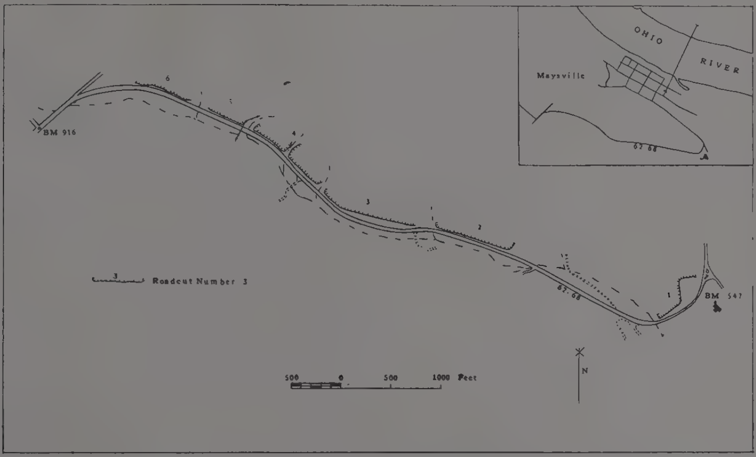

FIGURE 1. Planimetric map of a section of U. S. Highway 62–68 south of Maysville, Kentucky, along which are situated the roadside exposures of the Covington Group herein described.

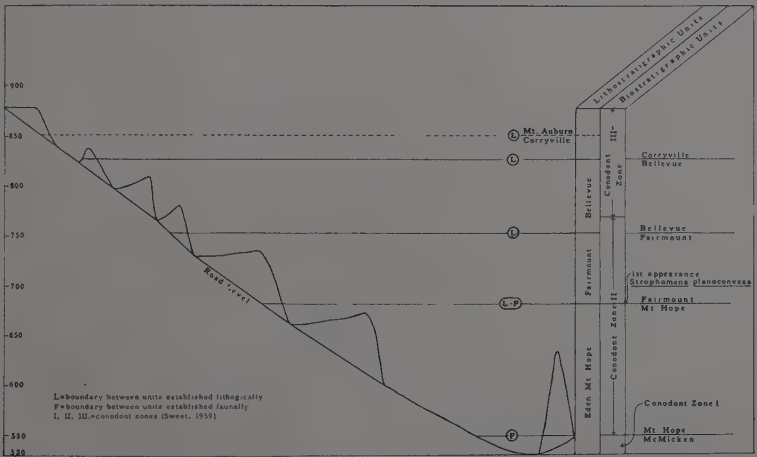

FIGURE 2. Diagrammatic cross-section of cuts mapped in figure 1. Elevation indicated in feet above mean sea level.

striking change takes place at the base of the Fairmount member, in the third roadcut. There, limestones abruptly begin to dominate and are so closely spaced that shale becomes a minor feature. Also at this point bedding planes become very irregular and the random position of brachiopod shells suggests current action. Isolated lenses of "shell hash" near the Fairmount base suggest considerable churning of sediments at this time.

From the Bellevue to the Mt. Auburn, limestones are very similar except for differences in silt-clay content. Most of these beds are irregular in thickness and very fossiliferous.

Fairview Formation

Mt. Hope Member.—Most limestones of the Mt. Hope member belong to classes 1, 4, and 5 (Weiss & Norman 1960). These constitute respectively 68, 25, and 7 percent of the limestones. Other than these, only one thin bed each of classes 2 and 3 occurs in the unit. A very accurate determination could be made in the Mt. Hope member because limestones are separated by large thicknesses of shale and form very distinct ledges. Class 1 limestone forms the thickest and most persistent ledges in this member. Classes 4 and 5 usually occur as thin interbeds in the shaly units of the member. The limestones and shales of the Mt. Hope are very evenly bedded and most limestones have smooth upper and lower surfaces. The lower two-thirds of the bedrock face in the first roadcut slopes about 25 degrees and limestones in this part weather light gray. Near the top of the cut, however, which is stratigraphically near the middle of the Mt. Hope, the slope steepens abruptly and the weathered color of the limestone changes to light brown. This is a result of the increase in thickness and resistance of class 1 limestones and closer and longer exposure to the zone of aeration.

The most important and abundant megafossils collected from the Mt. Hope are: "*Rafinesquina alternata*," *Onniella emacerata*, *O. multisecta*, *Escharopora falciformis*, *Platystrophia hopensis*, and *Zygospira modesta*. Bryozoans, including *Amplexopora septosa*, are very abundant in the Mt. Hope, but most are found in the shaly layers and are badly weathered. Crinoid colomnals are also abundant in both the limestones and the shales.

The Mt. Hope member, 134 ft thick, crops out along roadcuts 1 and 2 in addition to 18 ft of the Eden formation exposed at the base of roadcut number 1.

Fairmount Member.—The Fairmount consists of four distinct lithologic units. The lowest is a 25-ft interval of class 1, 2, and 3 limestones, in that order of abundance, with very thin-bedded shales. The limestones of this unit occur in wavy beds that are not persistent laterally. Some beds are composed entirely of shingled *Strophomena planoconvexa*.

Above is about 20 ft of class 5 limestones, some of which occur in beds exceeding 1 ft in thickness. These beds are more evenly bedded than those in the remainder of the member.

The third unit is 10 ft thick and consists mostly of class 2 and 3 limestones in equal abundance, in wavy beds 3 to 5 in. thick.

The outstanding characteristic of the Fairmount member is the great dominance of limestone over shale as compared with the underlying Mt. Hope member. Each of the limestone units contains interbedded shale, but the shales vary from 0.5 to 2 in. in thickness and cannot be distinguished from a short distance away.

Some of the most abundant megafossils collected from the Fairmount are: *Hebertella sinuata*, *Strophomena planoconvexa*, "*Rafinesquina alternata*," *Constellaria florida*, and *Halloporo dalei*.

The contact between the Mt. Hope and the Fairmount is exposed near the base of the third roadcut. The Fairmount is 71 ft thick.

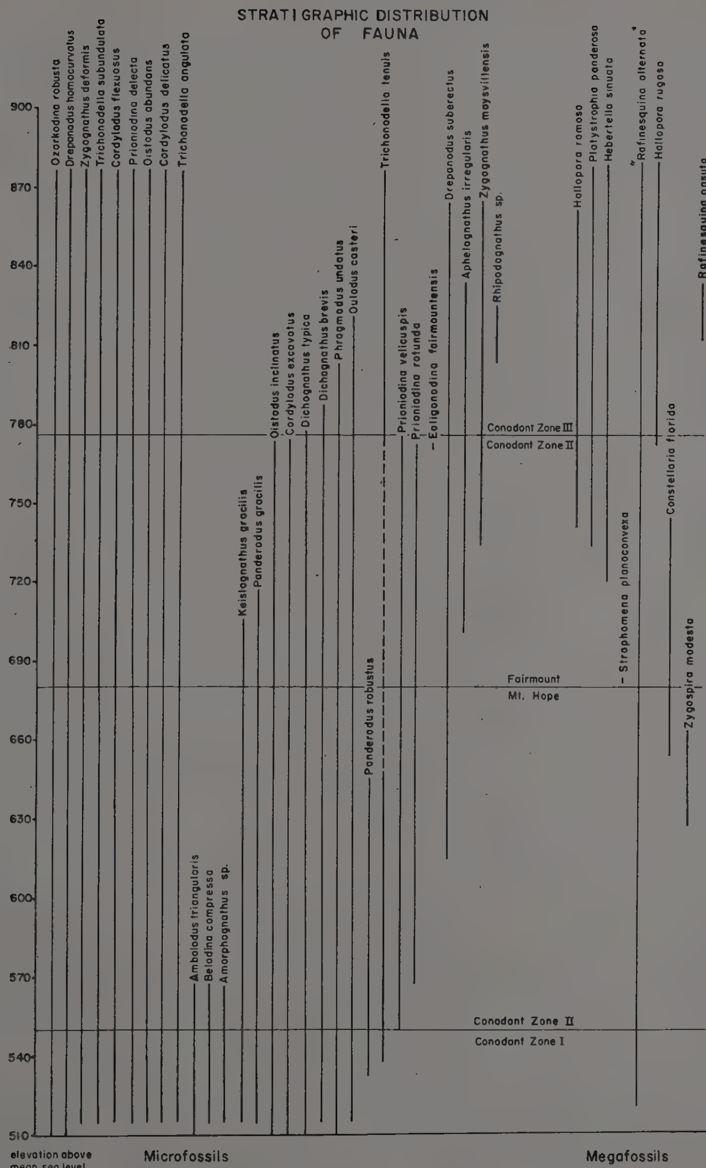

FIGURE 3. Ranges of the more significant mega- and microfossils in the Maysville roadcuts.

McMillan Formation

Bellevue Member.—The Bellevue consists of three distinct lithologic units. The lowest is 15 ft of class 4 and 5 limestones in almost equal abundance. The beds average 6 in. in thickness and change laterally from very evenly bedded to irregularly bedded in the space of a few tens of feet. These limestones weather light-blue-gray.

The 15-ft-thick second unit consists of mixed even and wavy beds of class 2 and 3 limestones, the weathered color of which is light yellow-brown. The highest Bellevue unit is 44 ft of class 1, 2, and 3 limestones in that order of abundance. The limestone beds average 3 in. in thickness and the interbedded shales average 0.5 to 2 in. in thickness. Even the thinnest shales of this unit contain discontinuous limestone layers. The limestones are irregularly bedded, but fairly continuous laterally. The weathered color is dark blue-gray.

Corryville Member.—The Corryville consists of class 1, 2, and 3 limestones in that order of abundance. The limestones average 8 to 12 in. thick and are evenly bedded with smooth upper and lower surfaces. The interbedded shales are thicker and more persistent than those in the underlying Bellevue. These beds which occur at the top of the fifth roadcut and on the flank of roadcut number 6 are in the zone of aeration and weather yellow-brown. Megafossils are very abundant in the Corryville. *Platystrophia ponderosa* becomes increasingly abundant near the top of the unit. The Corryville is 25 ft thick.

Mt. Auburn Member.—On the basis of lithology, the upper 25 ft of the highest roadcut (number 6) is Mt. Auburn. This unit consists of irregular beds of class 1, 2, and 3 limestones, in that order of abundance, and thin shales. *Platystrophia ponderosa* is the most abundant fossil in these highly fossiliferous beds. These rocks are similar to those in the Bellevue, which suggests a return to higher energy conditions in contrast with the underlying Corryville beds. The typical Mt. Auburn fauna was not found in this unit, but the lithology is similar to that of the Mt. Auburn at Cincinnati.

Contact Elevations and Unit Thicknesses of Covington Formations and Members

Contact	Location (cut and height in feet above base)	Elevation (feet above sea level)	Unit Thickness (in feet)
Corryville-Mt. Auburn	6th cut—15	852	Mt. Auburn—25
Bellevue-Corryville	5th cut—20	827	Corryville—25
Fairmount-Bellevue	4th cut—15	753	Bellevue—74
Mt. Hope-Fairmount	3rd cut—15	682	Fairmount—71
Eden-Mt. Hope	1st cut—18	548	Mt. Hope—134

THE FAUNAL SEQUENCE

The known vertical distribution of the more significant mega- and microfossils identified from the Maysville, Kentucky, section is shown in figure 3. Only the conodonts were studied in detail, for the sequence of Covington and Richmond conodont faunas is now well known (Branson, Mehl, and Branson, 1951; Sweet, et al., 1959; Pulse and Sweet, 1960), and it seemed desirable to locate in this section the well-established boundaries that separate distinct conodont zones elsewhere in the Cincinnati region.

The observed ranges of a few of the more abundant and diagnostic brachiopod and bryozoan species are shown in figure 3, primarily because several of these, singly or in combination with others, are widely used to identify faunal zones (or "formations") in the Cincinnati region.

Conodonts were collected from residues resulting from acetic acid digestion of

300-g limestone samples taken at irregular intervals through the section, but in no case farther apart than 4 ft. The upper portion of the section (above 690 ft) was sampled by R. R. Pulse and W. C. Sweet in the summer of 1958, and the conodonts obtained from their samples were made available to us for study. As figure 3 indicates, 29 conodont species were identified in samples from the Maysville, Kentucky, section. Many of these are long-ranging species and are of little detailed stratigraphic significance. Others, however, such as the group of three species found only below 570 ft, two species found only below 720 ft, and the three species found only between 550 and 775 ft, are not only represented by a considerable number of specimens, but are known to define rather persistent zones elsewhere in the Cincinnati region. The disappearance of *Phragmodus undatus* above 805 ft and the brief abundance of species of *Rhipidognathus* between 800 and 825 ft are anamalous, and no parallel sequence has heretofore been described from the Cincinnati region. That is, elsewhere, *Phragmodus undatus* is a common associate of the nine species listed on the left-hand side of figure 3, and in other sections ranges at least to the top of conodont zone III (Sweet, 1959). *Rhipidognathus*, on the other hand, has not previously been reported below conodont zone IV. This might suggest that the lower boundary of zone IV in the section at hand is between 800 and 805 ft; however, only four of the conodont species common between 800 ft and the top of the section have previously been reported from zone IV faunas, and in those faunas three of these species are very rare. Furthermore, as yet unpublished studies in progress at The Ohio State University, have established the presence of *Rhipidognathus* in the sub-Eden rocks of Kentucky.

The ranges of conodont species shown, and these brief explanations indicate that the boundary between Cincinnatian conodont zones I and II is at 550 ft in the Maysville, Kentucky, section; the boundary between zones II and III is at 775 ft, and the balance of the exposed section belongs in conodont zone III, as these zones were outlined by Sweet (1959).

Strophomena planoconvexa occurs in great abundance in some 20 ft of thick-bedded limestones above 680 ft, but is rare or absent above 700 ft and was not found at all below 680 ft. Elsewhere in the Cincinnati region, the first appearance of *Strophomena planoconvexa* has been taken to mark the base of the Fairmount member of the Fairview formation.

Platystrophia hopensis has been identified as low as 550 ft and at least as high as the base of roadcut number 2 (604 ft). *Platystrophia ponderosa* is present between 735 ft and the summit of the section, and occurs with abundant *Hebertella sinuata* and bryozoans.

Rafinesquina nasuta is not uncommon in rocks of Bellevue aspect between 815 and 830 ft. In other parts of the Cincinnati region, this distinctive brachiopod is commonly cited as an index to the Corryville member of the McMillan formation.

CONCLUSIONS

It has been the custom at Cincinnati to use the boundaries of faunal zones that are more or less coincident with distinctive lithologic units to mark the contacts between members and formations.

The principal results of our study have been to make careful measurements and lithologic descriptions of the Covington sequence exposed near Maysville, Kentucky, and to locate within this sequence zonal boundaries, based primarily on conodonts, which permit correlation of parts of this sequence with reference sections in Cincinnati as well as elsewhere in the Cincinnati region. In addition, our work demonstrates that rocks at Maysville, Kentucky, included within intervals defined more or less faunally at or near Cincinnati, Ohio, are different in many respects from rocks included in presumably the same faunally-defined intervals at Cincinnati. Eventually, we feel, it will be necessary to make more

critical distinctions between lithologic and faunal units in the Cincinnati region, but we feel hardly qualified to do this on the basis of our currently limited knowledge of distributional details respecting both the faunas and the rocks of the Covington group.

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Sciences in Communist China. *Sidney H. Gould*, Editor. Pub. No. 68 of the American Association for the Advancement of Science. 1961. xii+872 pp. $14.00.

This book is the report of a symposium held December 26 to 27, 1960, in New York City. It has sections devoted to Science and Society, Biological and Medical Sciences, Atmospheric and Earth Sciences, Mathematics and the Physical Sciences, and Engineering Sciences and Electronics. Each section comprises a series of papers by individual authors.

The authors were supplied photo-print copies of recent papers in their respective fields with which to make their appraisals. Most of the papers came out of libraries at Washington, and the copying was done by M. I. T., with a generous grant from the National Science Foundation.

The "Organization and Development of Science," by Harvard Professor J. M. H. Lindbeck, outlines the recent history of the efforts of the Communist leaders of China to build an organization of scientists who would quickly supply the basis for the industrial development of China. This has focused efforts upon engineering and the applied sciences, and it has almost prohibited basic research. Foreign-trained scientists, except those from Russia, have been handicapped, and the need has become apparent for more time in which to produce more red-loyal scientists than was envisioned in the 12-year plan of 1947.

Each of the authors of papers presents about the same appraisal—much progress to date, in spite of the limitations imposed (loyalty to Marxist-Leninist *science*, and results quickly usable), more progress to be expected in the next few years, but sympathy for scientists who are working under the existing pressures.

American scientists will find much of interest in the one or more papers which deal with their specific field of effort.

THOMAS H. LANGLOIS

The Shell-Bearing Land Snails of Ohio. *Celeste Taft.* O.S.U. Press, Ohio Biol. Surv. Bull. 1961. Paper-bound. xi+108 pp. $2.00.

This book is a contribution to knowledge of the distribution of these snails, made by the assembly of the records of other scientists and by the addition of many records made by the author. It is designed also to help the beginning collector, with suggestions for finding, cleaning, storing, and identifying the shells, and for recording the facts about each collection.

There are keys to families, and keys to genera and species. There is a brief description and an excellent drawing or two of each species, and there is an Ohio map, spotted to show where each species has been recorded. There is a list of snail records of the state, county by county, showing areas of adequacy as well as inadequacy of effort. There is a good index to round up this fine example of a scientist carrying her hobby to the point where it constitutes a real contribution to science.

THOMAS H. LANGLOIS

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